ESSAYS ON CONSERVATION AUCTIONS AND UNCERTAINTY IN PREFERENCES

A Dissertation

Presented to the Faculty of the Graduate School

of Cornell University

in Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy

by

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August 2018

ESSAYS ON CONSERVATION AUCTIONS AND UNCERTAINTY IN PREFERENCES

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Cornell University 2018

This dissertation includes two chapters. The first presents a new auction mechanism designed for conservation programs. Individuals compensated for conserving their land often extract substantial profits from the government or non-governmental agency funding the conservation program. These rents limit the amount of land which can be conserved, which decreases total surplus for society. The new auction mechanism, the Provision Point Reverse Auction, was designed to mitigate this rent-seeking behavior. This paper presents both theoretical and experimental evidence to substantiate the efficacy of the mechanism.

The second chapter considers the effect that preference uncertainty may have on two commonly observed behavioral anomalies: exchange asymmetries and the willingness-to-accept/willingness-to-pay disparity. This paper provides both theoretical and experimental evidence which suggests that uncertainty in preferences can explain at least part of these behavioral anomalies. The experiments rely on chocolate and a "taste" treatment, where individuals in a treatment group are allowed to taste a small amount of chocolate before making their trade or valuation decisions.

BIOGRAPHICAL SKETCH

Steven Otto is a doctoral candidate at Cornell University. Steven has studied applied economics with a focus on auction theory, game theory, experimental economics, environmental economics, and behavioral economics. Before attending Cornell, Steven received his Masters degree in economics from Tufts University, where he specialized in transportation economics. Prior to his graduate work, Steven attended the University of California, Berkeley, where he received a Bachelors degree in Environmental Economics and Policy.

This dissertation is dedicated to Greg Poe. Greg was a great man, advisor, and friend. Without his support, this work would not have been possible.

ACKNOWLEDGEMENTS

Thanks to David Just, William Schulze, Kent Messer, and Ariel Ortiz-Bobea. Your support has been invaluable. Special thanks to Kelsey Jack and Timothy Hubbard for their thoughtful comments and suggestions, as well as Steven Wilcox and Christina Korting. Additional thanks to Maulik Jagnani, Margaret Jodlowski, and Matt McGranaghan. Thanks to the Center for Behavioral Experimental Agri-Environmental Research (C-BEAR) and the USDA, who provided much of the funding for this research. Finally, thanks to Samantha Katagiri for innumerable acts of support and kindness over the last four years.

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CHAPTER 1

PROVISION POINT REVERSE AUCTION

1.1 Abstract

Rent-seeking behavior by participants in payment for environmental services auctions reduces the number of affordable contracts and decreases environmental protection. I propose a new auction mechanism, the provision point reverse auction (PPRA), to mitigate this rent-seeking behavior. The PPRA includes a public component where the probability of contract acceptance for one individual is affected by the offers of others. I provide theoretical support for the new mechanism which proves that optimal offering behavior in a PPRA results in less rent-seeking from sellers than a multiunit reverse discriminative auction, even in contexts where participants are risk neutral and place no utility on the welfare of their peers. I follow this theoretical work with laboratory experiments comparing the PPRA to the multiunit reverse discriminative auction and the reverse budget-constrained auction. The experiments yield average offers between 12.57% to 58.17% smaller in a PPRA compared to the alternate reverse discriminative auctions, with the exact value dependent upon the compared mechanism and the target number of contracts. The experimental results are also compared to the theoretical predictions for a uniform price auction. I find that the PPRA is less expensive than the uniform price auction, while the effect on social efficiency is dependent on parameter values. If the goods being purchased are associated with positive externalities, as we would expect in PES or conservation contexts, the reduction in rent-seeking behavior can increase total surplus.

1.2 Introduction

Payment for environmental services (PES) programs have become an increasingly important component of conservation and environmental protection. Many of these programs use reverse (or procurement) discriminative auctions to allocate contracts to individuals who provide the environmental service [27]. Reverse discriminative auctions involve one buyer and many sellers, where the winners of the auctions receive their offer (or bid) as payment. In most reverse discriminative auctions, the buyer has a fixed budget and accepts offers in ascending order until the budget has been exhausted. In such an auction, sellers must balance potential gains in expected profit from a higher offer against corresponding decreases in the probability the offer will be given a contract by the buyer. The higher the offer, the less likely a contract will be won and the potential profit will be realized. If these auctions are conducted for multiple rounds, sellers gain information about the costs of their peers each round and use that information to increase their profits at the expense of the buyer. More specifically, sellers slowly increase their offers until they discover the offer at which they would no longer receive a contract. I call submitting an offer above one's value "rent-seeking offers" or simply rent-seeking behavior.[1] Over time, as rent-seeking behavior becomes more pronounced, the buyer can afford fewer contracts and incurs a welfare loss. This is a particularly significant problem for payment for environmental services or conservation programs because each contract may provide an environmental positive externality. In such a case, a reduction in the number of contracts the buyer can purchase could decrease the environmental benefits from the program and decrease social welfare.

[1]Much of the literature uses the term "bid-shading" instead of rent-seeking offers. This term is not appropriate for reverse auctions, however, as "bid-shading" literally means to make a slight reduction in a bid, while in reverse auctions, individuals seek to increase profits by increasing their offers.

Given the large number of PES or conservation programs which use reverse discriminative auctions, including the Conservation Reserve Program (CRP) in the United States, the Auction for Landscape Recovery (ALR) in Australia, Challenge Funding in Scotland, and others, rent-seeking behavior is likely decreasing social welfare substantially.

With an eye toward mitigating rent-seeking behavior, and thus potentially increasing social welfare in conservation and PES contexts, I designed the "provision point reverse auction" (PPRA). The PPRA functions as a discriminative reverse auction in that there is one buyer with many sellers and each individual with an accepted offer receives their offer as payment. However, unlike other discriminative procurement auctions, in a PPRA the buyer declares a requirement that a prespecified number of offers must be affordable for any offers to be accepted. That is, if the buyer cannot afford to purchase that prespecified number of offers, given their budget constraint, then no contracts will be made with any individual.

Similar to a reverse discriminative auction, an individual participating in a provision point reverse auction must weigh increases in potential profit from a higher offer against corresponding decreases in the probability of realizing that profit. As an individual's offer becomes larger, it is also larger relative to the offers of their peers which decreases the probability the offer will be given a contract by the buyer. In a PPRA, however, a higher offer not only increases the offer relative to its peers, it also reduces the chance that the buyer can afford the prespecified number of units, which further lowers the probability of contract acceptance. I prove that this additional requirement incentivizes participants in a PPRA to submit offers closer to their costs, relative to a multiunit reverse discriminative auction.

The PPRA also includes a public component which serves as additional motivation for the mechanism. When an individual increases their offer, they negatively affect the expected profit of the other individuals in the auction by reducing the chance that any contracts are provided by the buyer. Thus, if individuals in a PPRA place positive utility on higher profits for their peers, they will be further incentivized to keep their offers close to their true costs. The author believes this is particularly likely to be true in close-knit rural or developing communities where PES programs are often implemented.

The PPRA would also make an attractive choice to governments or NGOs when the organizations are faced with thresholds for environmental value. For example, suppose a government agency is interested in restoring a polluted lake and reintroducing several species of fish. The agency estimates that a pollution reduction of $X\%$ would be required for the water to be habitable for the fish. If the agency was to use a budget-constrained auction to pay neighboring individuals to abate emissions, the agency would have no guarantee that the contracts necessary for the reintroduction of the fish would be affordable. Since the primary goal of the program is to reintroduce fish to the lake, the agency would be wasting their money if the pollution abatement totaled less than $X\%$ of total pollution. If the agency instead used a PPRA to pay individuals to reduce their emissions, the agency would either achieve the pollution reduction necessary for the reintroduction of the fish or keep their budget and attempt some other PES program. This hypothetical situation is similar to a voluntary agreement between local New York farmers and New York City over the Catskill-Delaware water system [1]. Instead of paying the farmers to implement environmentally friendly practices, the city threatened that if 15% of the farmers did not participate, costly regulation would take effect to achieve the desired water quality improvement.

This paper provides theoretical evidence which shows that, under various assumptions, optimal offers under a PPRA are less than the optimal offers under a multiunit reverse discriminative auction, given an opportunity cost. These theoretical predictions are supported by evidence from laboratory experiments. The experimental work presented here abstracts away from the public component of the mechanism to focus on proof of concept. Ten experimental sessions were conducted with 240 student participants in total. The experimental results suggest that the PPRA reduces accepted offers by between 21.55% to 58.17% or 12.57% to 21.59%, when compared to a multiunit reverse discriminative auction or a budget-constrained multiunit reverse discriminative auction, respectively, with the exact value dependent upon the target number of contracts. The effect on offering behavior is particularly pronounced for the lowest offers, which are also the offers of greatest interest to the buyer.

1.3 Literature Review

Environmental goods or services are generally not exchanged on open markets and so do not have an easily observable price. Auctions are a convenient method for exchange when the values for a good are unknown, and thus present an attractive choice to policy makers interested in purchasing environmental services. However, there are many types of auctions and it is not a priori obvious which auction format should be chosen, if an auction should be used at all. Vickrey's seminal papers on auction theory, and much of the literature that followed, relies upon a "single independent private values" (SIPV) model [49, 50]. In the SIPV model: 1) there is a single indivisible unit available for sale, 2) each bidder knows their own private valuation, 3) all bidders are identical, 4) the valuations are independent and identically distributed, and 5) all bidders are risk neutral [52]. Within this framework, there are four formats: the Dutch auction, the English auction, the first-price sealed bid auction, and the second-price sealed bid auction. The famous Revenue Equivalence Theorem (RET) states that the auctioneer receives the same revenue, regardless of the chosen format [35, 41, 49]. However, markets for environmental services do not satisfy many of the assumptions required for the RET to hold, and so we cannot apply this useful result to questions regarding conservation and PES auctions.

One key difference between conservation and PES auctions and auctions in an SIPV model is that auctions for environmental services are generally multiunit procurement auctions. That is, conservation or PES auctions generally involve one buyer purchasing multiple units of a good from multiple sellers. Unfortunately, the literature is less developed on the topic of multiunit procurement auctions than on other mechanisms, particularly for auctions where the buyer is restricted by a budget [36, 5, 15, 27, 46]. Harris and Raviv (1981) and Cox et al. (1984) generalized Vickrey's original results and provided optimal offer functions for multiunit discriminative auctions with symmetric, risk neutral sellers whose costs are drawn from a uniform distribution [17, 10]. Hailu et al. (2005) extended this research and provided the optimal offer function for the reverse (or procurement) multiunit discriminative auction, which they call a "target-constrained" (as opposed to budget-constrained) auction [15]. To the best of my knowledge, no one has specified an optimal offer function for a multiunit procurement auction where the buyer is constrained by a budget. Without more robust theoretical guidance from the literature, researchers and policy makers are forced to rely on experience and experimental evidence when making their decisions about how to purchase environmental services.

When using auctions in payment for environmental services (PES) programs, buyers frequently opt for either a uniform second price auction or a discriminative auction [27]. In a uniform second price procurement auction, all individuals who submit winning offers are paid the first rejected offer. In settings where each seller has only one unit of the good to sell, individuals have the incentive to offer their true cost to the seller because increasing one's offer cannot increase their own payoff. In a discriminative procurement auction, individuals who submit winning offers receive their offers as payment, analogous to a first price auction. Unlike the uniform second price procurement auction, in the discriminative procurement auction the optimal offering strategy is to submit an offer higher than one's true cost. Because only individual sellers have full information on their true costs, this offering behavior leads to information rents for the sellers.

There is disagreement in the literature about the relative cost effectiveness of the uniform second price and discriminative auctions from the perspective of the buyer [8, 14, 6]. Each mechanism's efficiency and cost effectiveness is a function of the cost structure of the individual participants and the assumptions regarding information and communication. In their comprehensive review on the theoretical and empirical literature regarding conservation contracts, Latacz-Lohmann and Schilizzi provided several reasons that explain why funding agencies often choose discriminative procurement auctions over uniform price auctions. [27] First, uniform procurement auctions are riskier for sellers as both the probability of acceptance and the payoff are uncertain. This could lead to fewer participants in the auction, which may decrease competition and increase offers. Second, individuals with low costs would gain the most from the auction. This may be viewed as unfair by many higher cost individuals. Third, uniform price auctions are more complicated than discriminative procurement auctions, and thus may lead to poor offering strategies or lower participation levels.

Posted offer or flat-rate offer systems have been proposed as an alternative to auctions in conservation and payment for environmental services settings. In these programs, the buyer offers all individuals a fixed payment for participation in a program which provides an environmental or conservation service for the buyer. However, in a posted offer market, the price must be determined ex ante. In situations where there is uncertainty regarding the costs and benefits of the good to be provided (a particularly large issue in environmental economics), auction mechanisms increase efficiency by resulting in a market-clearing price. Latacz-Lohmann and Van der Hamsvoort, in their paper on auction theory and conservation contracts, show that "auctions are generally superior to a posted-price offer system for providing low-cost solutions to the provision of environmental benefits, because they introduce an element of competition between farmers" [28]. Other authors have expanded upon this by demonstrating that posted offer systems result in more contracts than discriminative procurement auctions, but that individuals who receive contracts in a posted-offer system are far less likely to fulfill the terms of the agreement than individuals participating in an auction. For example, in an experiment for tree-planting contracts, Jack finds that while 99.5% of the posted-offers were accepted, those who received contracts were, on average, far more likely to keep their trees alive [20].

To increase the efficiency of PES or conservation programs which use discriminative auction formats, I propose the provision point reverse auction (PPRA). The PPRA functions as a discriminative procurement auction with the added requirement that a certain number of units are purchased by the buyer, given a constant, exogenous budget. For example, if the provision point requirement is

80% participation, but the buyer can only afford contracts for 75% of the sellers, then no contracts will be offered and the buyer will keep their money. Section 1.4 will provide further details.

The PPRA is connected to the research conducted on the provision point mechanism (PPM) for voluntary contributions to public goods [11, 33, 43, 42]. In a provision point mechanism, a public good is provided only if the total contributions exceed some predetermined threshold. If the total contributions do not exceed this "provision point," then all contributions are refunded to the participants and no amount of the public good is provided. The PPRA is essentially the reverse auction form of the provision point mechanism: instead of a total contribution requirement, the sum of the lowest cost offers must be less than the budget and the potential profits from the auction can be viewed as the public good offered through the mechanism.

The closest paper to the provision point reverse auction, as formulated here, is a contingent valuation study which attempted to reduce the upward bias in willingness to accept estimates using a provision point. Their mechanism is called a provision point mechanism (PPM), after the previous literature on contributions to public goods [7]. This paper expands upon the work of Bush et al. by generalizing their mechanism to an auction with many possible provision point requirements and tests the auction mechanism with real money in an experimental setting. This paper additionally provides theoretical support to substantiate the experimental evidence.

Some related research has focused on conditional subsidies to individuals in settings with voluntary contributions to public goods. More specifically, additional subsidies can be paid out to farmers in a conservation or payment for environmental services program if a certain amount of service is provided. For example, Le Coent, Preget, and Thoyer find that a mechanism which provides a subsidy conditional on some threshold being met improves both the efficiency and the efficacy of the mechanism [29]. A second paper shows that a similar "conditional collective bonus" can improve farmer participation and increase total land enrollment in a payment for environmental services setting, while simultaneously decreasing costs [26]. This is a potentially fruitful extension of the provision point reverse auction. The PPRA provides contracts conditional on a certain amount of environmental or conservation service being affordable. This could be stacked with a "conditional bonus" paid to individuals who receive contracts when the provision point requirement is met.

Much of the recent literature on conservation auctions has focused on special features of the conservation and payment for environmental services settings which create complications when deciding upon an optimal auction mechanism. The focus of this paper, however, is on "proof of concept" for the mechanism, and so abstracts away from many of these issues. A short examination of some of these problems, however, provides useful insights into both how this mechanism might perform in more externally valid settings and potential future areas of research.

For example, environmental or conservation benefits are often a function of the spatial location of the conserved land; conserved land which is more compact will provide better habitats for many species. This is a particularly important issue for the construction of "wildlife corridors" [44]. Ideally, auctions in settings which include this spatial component would select contracts based on a "total environmental value" function which incorporates this spatial component. If auctions do not use such a function, they are likely to under-procure environmental or conservation value. The spatial nature of the problem, however, creates substantial computational difficulties. For example, even in a setting with only 24 possible plots of land to conserve, there are over 16 million possible combinations of land to consider. With 30 plots of land, this set of possible combinations increases to 1 billion sets of land, and to over 1 trillion possible sets of land with 40 plots of land. This computational complexity makes it difficult for auctions in spatial settings to run in real time, or even over extended periods of time, and so many scholars have devised alternative solutions which do not consider the spatial element of conservation or environmental value, but which attempt to incentivize individuals to conserve their land in clusters [37, 51, 2]. Given that the provision point reverse auction will likely work best in settings with environmental thresholds, correctly specifying the environmental benefits function is critical. As a result, combining a provision point with a spatial auction presents a fruitful area for future research.

Another complication for conservation auctions is the availability of public information on historical auction results. Messer et al. (2017) examine the effect of public information provided by the buyer on seller behavior in reserve auctions which trade in environmental services [34]. The authors find that the sellers use this public information to increase rents. Further, they find that auctions with variable budgets are more likely to lead to efficient outcomes. This complicates the already difficult theory behind budget-constrained auctions. Given that the budget selection is critical for the success of the provision point reverse auction, the performance of the mechanism when the budget is random or changes randomly overtime is another fruitful area for future research, particularly if a random budget can increase the efficiency of the PPRA.

Finally, scholars have shown that the probability an individual will follow through on a contract is a function of the mechanism choice by the buyer [20, 21]. This is important for the provision point reverse auction as well, particularly if the provision point requirement is set at an environmentally important threshold. For example, suppose that the provision point requirement is set so that just enough pollution reduction will occur to allow fish to return to a local lake. If a non-trivial portion of the individuals contracted to reduce pollution do not respect their contracts, then the government will spend money and fail to reduce pollution sufficiently to achieve their goal of reintroducing fish to the lake. This problem can be mitigated if the percentage of individuals who will break their contracts can be estimated. However, the lab is not an appropriate setting for such analysis, and field experiments would likely be required. The problem may also be mitigated by a threat from the government. For example, when New York City was negotiating with farmers around the Catskill-Delaware to reduce pollution, they threatened to implement costly regulations on the farmers if an insufficient number of them agreed to participate in the voluntary pollution abatement program [1].

1.4 Theory and Model

The theory section is split into two parts. In the first subsection, I re-derive the symmetric Bayesian Nash Equilibrium optimal offer function for a multiunit reverse discriminative auction and demonstrate several properties of that optimal offer function. The second subsection introduces the provision point reverse auction, characterizes its expected profit function, and derives predictions for optimal behavior in a PPRA compared to a multiunit reverse discriminative auction.

1.4.1 Multiunit Reverse Discriminative Optimal Offer Function

Let $n \in \mathbb{N}$ denote the number of participants in an auction. In a multiunit reverse discriminative auction, the buyer is interested in purchasing $p \in \mathbb{N}$ units of a good from the n sellers. This paper refers to p as the "target" of the auction. Further, let $B \in (0, \infty)$ denote the budget if the auction is a budget-constrained multiunit auction, $v_i \in [0, 1]$ denote individual i's opportunity cost or value, $o_i \in [0, \infty)$ denote their offer, $O_j(v_j)$ denote the assumed offering behavior of the other participants as a function of their values, and $O_j^{-1}(o_j)$ denote its inverse. To simplify the theory and computations, this paper makes the common assumption that all values are drawn from a standard uniform distribution. All of the auctions considered have the following properties:

1) More than one unit is being exchanged in each round;
2) The auctions have one buyer with multiple sellers. These auctions are known as reverse (or procurement) auctions;
3) Values (opportunity costs) are independently drawn, so an individual's value provides no information about the values of the other participants;
4) Each bidder knows their own value but they do not know the value of any other participant;
5) All participants, as well as the units they are trying to sell, are symmetrical and indistinguishable;

In addition, this paper also assumes all participants are risk neutral.

Much of the following theory relies upon order statistics, so a brief set of definitions is in order. (See Wolfstetter (1996) for a brief and exceedingly useful overview of order statistics and auction theory.) Out of a set of n draws from a distribution with probability density function $f(x)$ and cumulative distribution function $F(x)$, the random variable $V_{(r)}$, which represents the r^{th} lowest draw, is called the r^{th} order statistic. The probability density function of $V_{(r)}$ is given by

$$f_{V_{(r)}}(x) = \frac{n!}{(r-1)!(n-1)!} F(x)^{r-1}(1-F(x))^{n-r} f(x) \tag{1.1}$$

For a standard uniform distribution, $f(x) = 1$ and $F(x) = x$, so that the above simplifies to

$$f_{V_{(r)}}(x) = \frac{n!}{(r-1)!(n-1)!} x^{r-1}(1-x)^{n-r} \tag{1.2}$$

Notice that this is a beta distribution, $\mathrm{B}(r, n+1-r)$.

The auction formats considered have expected profit functions given by:

$$E[\Pi] = (o_i - v_i) \times Pr(o_i \in \mathbb{O}) \tag{1.3}$$

where $\mathbb{O}$ is the set of accepted contracts. The form of $Pr(o_i \in \mathbb{O})$ depends on the auction used, as well as the parameter values chosen. As an individual increases their offer, potential profit, given by $(o_i - v_i)$, increases, but $Pr(o_i \in \mathbb{O})$, the probability of realizing the potential profit, decreases. Thus, picking the optimal offer for a given value requires balancing these two effects.

For the multiunit reverse discriminative auction auction, expected profit is given by:

$$E[\Pi] = (o_i - v_i) \times Pr(o_i < O_{(p)}) \tag{1.4}$$

where $O_{(p)}$ is the p^{th} lowest offer submitted by the other participants. From (1.2) above and assuming that all values are drawn from a standard uniform distribution, the probability that an individual's offer is one of the p smallest offers is given by the function:

$$g(n, p, O_j^{-1}(o_i)) = \frac{(n-1)!}{(p-1)!(n-p-1)!} \int_{O_j^{-1}(o_i)}^{1} u^{p-1}(1-u)^{n-p-1} du \tag{1.5}$$

Intuitively, the g function takes in an individual's offer, o_i, and transforms it into an opportunity cost through $O_j^{-1}(\cdot)$. $O_j^{-1}(o_i)$ denotes the opportunity cost draw that would result in the offer o_i from the other participants in the auction, assuming the common offering behavior $O_j(\cdot)$. This opportunity cost can then be used to calculate the probability the offer is one of the p smallest offers using the properties of order statistics and the given distribution for opportunity costs. From this point on, $g(n, p, O_j^{-1}(o_i))$ will be simplified as $g(O_j^{-1}(o_i))$.

Given an expected profit function, we are interested in the offer which, for each possible value, maximizes expected profit. That is, we are interested in a function which takes in an individual's opportunity cost and returns their expected profit maximizing offer. Even more, we are interested in the offer function which is also a symmetric Bayesian Nash equilibrium. A symmetric Bayesian Nash equilibrium occurs when the best response to a given offer function is that offer function. More specifically, a symmetric Bayesian Nash equilibrium is an optimal offer function where, if an individual is participating in an auction where they assume the other individuals submit offers according to an offer function $O_j(v_j)$, the optimal response is to also submit offers according to $O_j(v_j)$.

Hailu, Schilizzi and Thoyer derive the symmetric Bayesian Nash equilibrium for a multiunit reverse auction. [15] A re-derivation and confirmation of their results is included in the appendix. (Propositions 1 and 2 are expansions upon Hailu et al's results.) In a multiunit reverse auction (also known as a target-constrained auction), a participant in the auction is interested in the probability that their offer will be one of the p lowest offers out of the n offers submitted by the n participants. The symmetric Bayesian Nash equilibrium for a multiunit procurement auction is:

$$O^*_{i,TC}(v_i) = \frac{\int_{v_i}^{1} u^p(1-u)^{n-p-1}du}{\int_{v_i}^{1} u^{p-1}(1-u)^{n-p-1}du} \tag{1.6}$$

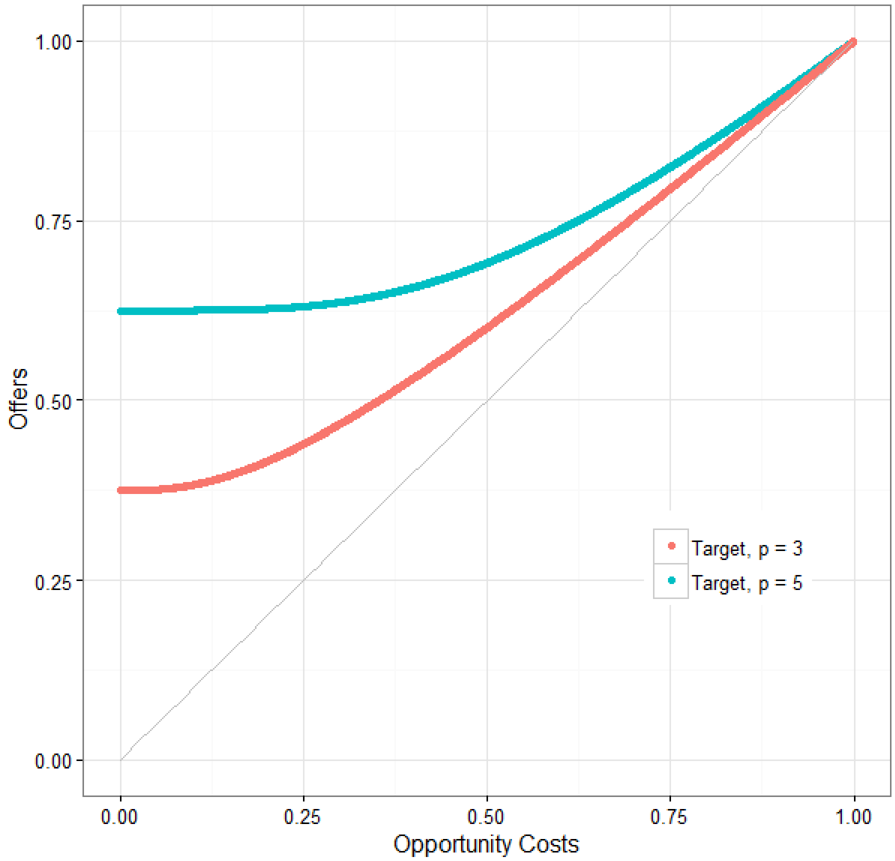
The optimal offer function, $O^*_{i,TC}(v_i)$, takes in an individual's value and returns the optimal offer (i.e., the offer which maximizes expected profit) for that value. Figure 1.1 displays this optimal offer function, assuming $n = 8$ and $p = 5$ or $p = 3$, where it can be clearly seen that low-value individuals can extract substantial rents (equivalent to many times their opportunity costs) from the buyer. Intuitively, for lower opportunity costs, an individual can increase their offer above their opportunity cost to increase potential profits while only slightly decreasing the probability that their offer will receive a contract. On the other hand, when a high opportunity cost individual submits an offer higher than their opportunity cost, they have a small chance that their offer will be accepted. As a result, the optimal offer function converges to cost revealing offers as an individual's opportunity cost approaches 1.

Note that $O^*_{i,TC}(v_i)$ is not defined when $v_i = 1$. Despite this, we can still make the following claim.

Proposition 1. *As v_i approaches 1, $O^*_{i,TC}(v_i)$ converges to 1.*

Proof. For all $v_i \in (0,1)$, the numerator of $O^*_{i,TC}(v_i)$ is less than the denominator, so $O^*_{i,TC}(v_i)$ is bounded above by 1 for $v_i \in (0,1)$. Further, given that a non-negative expected profit requires $O^*_{i,TC}(v_i) \geq v_i$, $O^*_{i,TC}(v_i)$ is bounded below by v_i. Both $y = v_i$ and $y = 1$ converge to 1 as v_i approaches 1, so $O^*_{i,TC}(v_i)$ converges to 1 as v_i approaches 1 by the sandwich theorem. □

Figure 1.1: Target-Constrained Auction: n = 8, p = 5



It is also informative (and will be useful in future proofs) to show that $O^*_{i,TC}(v_i)$ is a strictly increasing function in v_i. But first, the following proposition and proof are made simpler by rewriting $O^*_{i,TC}(v_i)$ with the regularized beta function, given by:

$$I_x(a,b) = \frac{\int_0^x t^{a-1}(1-t)^{b-1}dt}{B(a,b)}$$

To rewrite $O^*_{i,TC}(v_i)$ in terms of the regularized beta function, we multiply the numerator and denominator of $O^*_{i,TC}(v_i)$ by $\frac{B(p+1,n-p)}{B(p+1,n-p)}$, where $B(p+1,n-p)$ represents the beta function with parameters $p+1$ and $n-p$. This yields

$$\begin{aligned} O^*_{i,TC}(v_i) &= \frac{\int_{v_i}^1 u^p(1-u)^{n-p-1}du \times \frac{B(p+1,n-p)}{B(p+1,n-p)}}{\int_{v_i}^1 u^{p-1}(1-u)^{n-p-1}du \times \frac{B(p,n-p)}{B(p,n-p)}} \\ &= \frac{1-I_{v_i}(p+1,n-p)}{1-I_{v_i}(p,n-p)} \times \frac{B(p+1,n-p)}{B(p,n-p)} \end{aligned} \tag{1.7}$$

Given that $B(x,y) = \frac{\Gamma(x)\Gamma(y)}{\Gamma(x+y)}$, (1.7) simplifies to

$$O^*_{i,TC}(v_i) = \frac{1 - I_{v_i}(p+1, n-p)}{1 - I_{v_i}(p, n-p)} \times \frac{p}{n} \tag{1.8}$$

One convenient property of the regularized beta is that

$$I_{v_i}(p+1, n-p) = I_{v_i}(p, n-p) - \frac{v_i^p (1-v_i)^{n-p-1}}{pB(p, n-p)} \tag{1.9}$$

and thus (1.8) can be rewritten as:

$$\begin{aligned} O^*_{i,TC}(v_i) &= \frac{1 - I_{v_i}(p, n-p) + \frac{v_i^p (1-v_i)^{n-p-1}}{pB(p,n-p)}}{1 - I_{v_i}(p, n-p)} \times \frac{p}{n} \\ &= \frac{p}{n} + \frac{v_i^p (1-v_i)^{n-p-1}}{nB(p, n-p)(1 - I_{v_i}(p, n-p))} \end{aligned} \tag{1.10}$$

Having rewritten $O^*_{i,TC}(v_i)$ as above, we can describe the first derivative of the optimal offer function.

Proposition 2. *$O^*_{i,TC}(v_i)$ is a strictly increasing function of v_i for $v_i \in [0,1)$.*

Proof. Applying the quotient rule, the derivative of $O^*_{i,TC}(v_i)$ with respect to v_i is

$$\begin{aligned} \frac{\partial O^*_{i,TC}(v_i)}{\partial v_i} &= \Big[((pv_i^{p-1}(1-v_i)^{n-p-1} + (n-p-1)(1-v_i)^{n-p-2} v_i^p) \times \\ &(nB(p,n-p)(1 - I_{v_i}(p,n-p))) + nv_i^p (1-v_i)^{n-p-1} v_i^{p-1} (1-v_i)^{n-p-1})\Big] / \\ &n^2 B(p,n-p)^2 (1 - I_{v_i}(p,n-p))^2 \end{aligned} \tag{1.11}$$

Factoring out v_i^{p-1} and $(1-v_i)^{n-2p-2}$, and dividing the numerator and denominator by n yields

$$\frac{\partial O^*_{i,TC}(v_i)}{\partial v_i} = \frac{v_i^{p-1}(1-v_i)^{n-2p-2}((1-v_i)^p (p - nv_i + v_i) B(p,n-p)(1 - I_{v_i}(p,n-p)) + (1-v_i)^n v_i^p)}{nB(p,n-p)^2 (1 - I_{v_i}(p,n-p))^2} \tag{1.12}$$

We want to show that

$$0 < \frac{v_i^{p-1}(1-v_i)^{n-2p-2}((1-v_i)^p(p-nv_i+v_i)B(p,n-p)(1-I_{v_i}(p,n-p))+(1-v_i)^n v_i^p)}{nB(p,n-p)^2(1-I_{v_i}(p,n-p))^2} \tag{1.13}$$

for all $v_i \in (0,1)$. Note that $v_i^{p-1}(1-v_i)^{n-2p-2}$ and $pB(p,n-p)^2(1-I_{v_i}(p,n-p))^2$ are both positive, and thus both can be cancelled out without affecting the direction of the inequality. Inequality (1.13) thus holds when

$$-(1-v_i)^p(p-nv_i+v_i)B(p,n-p)(1-I_{v_i}(p,n-p)) < (1-v_i)^n v_i^p \tag{1.14}$$

Dividing both sides by $n(1-v_i)^pB(p,n-p)(1-I_{v_i}(p,n-p))$ yields

$$-\left(\frac{p}{n} - v_i + \frac{v_i}{n}\right) < \frac{(1-v_i)^{n-p}v_i^p}{nB(p,n-p)(1-I_{v_i}(p,n-p))} \tag{1.15}$$

A slight rearrangement of terms yields

$$v_i\left(1-\frac{1}{n}\right) < \frac{p}{n} + \frac{(1-v_i)^{n-p}v_i^p}{nB(p,n-p)(1-I_{v_i}(p,n-p))} \tag{1.16}$$

Notice that the righthand side of (1.16) is the optimal offer function for $O^*_{i,TC}(v_i)$ from (1.10). Also note that $(1-\frac{1}{n}) < 1$. Equation (1.16) thus implies (1.17) below.

$$v_i\left(1-\frac{1}{n}\right) < v_i < O^*_{i,TC}(v_i) \tag{1.17}$$

Given that profit maximization requires $O^*_{i,TC}(v_i) > v_i$ for all $v_i \in [0,1)$, the optimal offer function is increasing for all $v_i \in [0,1)$. □

This proposition will prove critical when comparing optimal offering behavior between the multiunit reverse discriminative auction and the provision point reverse auction.

1.4.2 Provision Point Reverse Auction

The provision point reverse auction is a discriminative reverse auction with the added requirement that p of the n total offers must be affordable for any contracts to be made, given the exogenous budget B. I call this additional requirement the "provision point requirement." In a PPRA, an individual has to consider several factors when choosing their offer. Like most discriminative auctions, the individual must weigh the increase in potential profit from a higher offer against the decreased probability that a given offer will be accepted. In a PPRA, a higher offer decreases the probability of contract acceptance through two avenues. First, a higher offer makes it less likely that the offer will be one of the p lowest offers, and thus less likely that the offer will receive one of the p possible contracts. Second, a higher offer decreases the probability that the provision point requirement will be met, and thus reduces the probability that any contracts will be provided.

The provision point requirement can be viewed as an "average" reservation price. In reverse auctions, a reservation price is the highest acceptable offer a seller can make to the buyer. By setting the budget and the provision point, the buyer implies that they will not spend more than B/p, on average, for the p units. The average reservation price allows individuals with opportunity costs higher than the average reservation price to receive a contract by incentivizing lower opportunity cost individuals to submit lower offers. For example, in a PPRA, an individual can submit a bid higher than B/p and still receive a contract if at least one of the other p lowest offers is less than B/p, while this is not possible in an auction with a reservation price of B/p.

Looking back to (3), in a PPRA, the probability that an offer, o_i, receives a contract is the probability that o_i is one of the p lowest offers times the probability that the provision point requirement is met given that o_i is one of the p lowest offers. If either the provision point requirement is not met or o_i is not one of the p lowest offers, then o_i will not receive a contract. Thus, the expected profit function for an individual participating in a PPRA is given by

$$E[\Pi] = (o_i - v_i) \times Pr(o_i < O_{(p)}) \times Pr\left(\sum_{j=1}^{p-1} O_{(j)} + o_i \leq B | o_i < O_{(p)}\right) \tag{1.18}$$

where the third term on the right-hand side is the probability that the provision point requirement is met, given that o_i is one of the p lowest offers.

When considering the probability the provision point requirement will be met, an individual is interested in the expected value of the excess budget, given the sum of the expected offers of the other low cost individuals. That is, the individual is interested in the difference between the budget and what they expect the sum of the other $p - 1$ lowest bids to be. If their offer is one of the p lowest and is greater than the excess budget, the provision point requirement will not be met because the sum of the p lowest offers will exceed the budget. On the other hand, if their offer is one of the p lowest and is less than the excess budget, the provision point requirement will be met as the sum of the p lowest offers will be less than the budget. If we assume that the other individuals submit offers according to a common offer function, $O_j(\cdot)$, and we assume the budget, B, is given exogenously, then the expected value of the excess budget given that o_i is one of the p lowest offers, denoted by Θ, is

$$E[\Theta] = B - \sum_{j=1}^{p-1} E[O_j(v_{(j)}) | o_i < o_{(p)}] \tag{1.19}$$

where $v_{(j)}$ is the jth lowest opportunity cost. Intuitively, the expected value of the excess budget tells an individual the expected offer which, on average, would just meet the provision point requirement. The variance in the distribution of the excess budget suggests the degree to which the probability the provision point requirement will be met changes with small changes in an individual's offer. Gupta and Sobel (1958) show that the sum of standard uniform order statistics is asymptotically normal. Thus, if the assumed offering behavior, $O_j(v_j)$, is cost-revealing, then this distribution would be asymptotically normal. However, because individuals will not submit cost-revealing offers, we cannot use this approximation. In fact, given that the offer function for other individuals will generally not have a closed form, it seems unlikely that a closed form representation of (1.19) exists.

To summarize, an individual's probability of submitting one of the p lowest offers, given their offer and assumed offering behavior of other individuals, is described by (1.5). Given the individual submits one of the p lowest offers, the probability that the provision point requirement is met is given by the probability that o_i is less than the excess budget, with the expected value of the excess budget given in (1.19).

Before we proceed further, we require the following axiom which is suggested by Proposition 1.

Axiom 1. *If the probability that an individual receives a contract is 0 in any auction, then their optimal offering behavior is to submit an offer at their opportunity cost.*

This axiom is important because it defines optimal offering behavior for values for which the optimal offer function might not be defined. For example, the optimal offer function for the multiunit reverse discriminative auction (see (1.6)) is not defined when $v_i = 1$. A natural conclusion from this fact is that the optimal offer for individuals with $v_i = 1$ is 1 in both the multiunit reverse discriminative auction and the provision point reverse auction. With this background, I provide the following proposition.

Proposition 3. *Suppose $O^*_{i,TC}(v_i|n,p)$ is the symmetric Bayesian Nash equilibrium optimal offer function for the multiunit reverse discriminative auction with a target of $p < n$ and $O^*_{i,PP}(v_i|n,p,B)$ is a symmetric Bayesian Nash equilibrium optimal offer function for the provision point reverse auction with a provision point requirement of $p < n$ and a budget of B. (From this point on, $O^*_{i,TC}(v_i|n,p)$ and $O^*_{i,PP}(v_i|n,p,B)$ will be simplified as $O^*_{i,TC}(v_i)$ and $O^*_{i,PP}(v_i)$, respectively.) Additionally, assume Axiom 1 holds. Then $O^*_{i,TC}(v_i) = O^*_{i,PP}(v_i)$ if and only if either i) any single participant in the auction cannot affect the probability that the provision point requirement is met by increasing or decreasing their offer or ii) $v_i = 1$.*

Proof. The expected profit function for the multiunit reverse discriminative auction is given by (2). Let $g(n,p,o_i)$ represent the probability that an offer is one of the p lowest and let $o^*_{i,TC}$ represent the optimal offer, given v_i, in a multiunit reverse discriminative auction. Note that $g(n,p,o_i)$ is a decreasing function in o_i; the larger o_i, the less likely it is one of the p lowest offers. Expected profit for the multiunit reverse discriminative auction is maximized where the first order conditions are met:

$$(o^*_{i,TC} - v_i) = \frac{-g(n,p,o^*_{i,TC})}{\left(\dfrac{\partial g(n,p,o^*_{i,TC})}{\partial o^*_{i,TC}}\right)} \tag{1.20}$$

Let $w(n,p,B,o_i)$ represent the probability that the provision point requirement will be met and let $o^*_{i,PP}$ represent the optimal offer, given v_i, in a provision point reverse auction. Note that $w(n,p,B,o_i)$ is a non-increasing function of o_i; as a given offer gets larger, the likelihood that the provision point requirement is met does not increase. Then the first order condition for profit maximization for the

PPRA is:

$$(o^*_{i,PP}-v_i) = \frac{-g(n,p,o^*_{i,PP}) \times w(n,p,B,o^*_{i,PP})}{\left(\frac{\partial g(n,p,o^*_{i,PP})}{\partial o^*_{i,PP}} \times w(n,p,B,o^*_{i,PP}) + \frac{\partial w(n,p,B,o^*_{i,PP})}{\partial o^*_{i,PP}} \times g(n,p,o^*_{i,PP})\right)} \tag{1.21}$$

Suppose $O^*_{i,TC}(v_i) = O^*_{i,PP}(v_i)$. Then $o^*_{i,TC} = o^*_{i,PP}$ for all v_i. Multiplying the top and bottom of the right-hand side of (1.21) by the reciprocal of its numerator yields

$$(o^*_{i,PP}-v_i) = \frac{-1}{\left(\frac{\partial g(n,p,o^*_{i,PP})}{\partial o^*_{i,PP}} \times \frac{1}{g(n,p,o^*_{i,PP})} + \frac{\partial w(n,p,B,o^*_{i,PP})}{\partial o^*_{i,PP}} \times \frac{1}{w(n,p,B,o_{i,PP^*})}\right)} \tag{1.22}$$

From (1.20), and given that $o^*_{i,TC} = o^*_{i,PP}$, we have

$$(o^*_{i,PP}-v_i) = \frac{-1}{\left(\frac{-1}{(o^*_{i,PP}-v_i)} + \frac{\partial w(n,p,B,o^*_{i,PP})}{\partial o^*_{i,PP}} \times \frac{1}{w(n,p,B,o_{i,PP^*})}\right)} \tag{1.23}$$

Multiplying both sides by the denominator of the right-hand side yields

$$(o^*_{i,PP}-v_i) \times \left(\frac{-1}{(o^*_{i,PP}-v_i)} + \frac{\partial w(n,p,B,o^*_{i,PP})}{\partial o^*_{i,PP}} \times \frac{1}{w(n,p,B,o_{i,PP^*})}\right) = -1 \tag{1.24}$$

which simplifies to

$$0 = (o^*_{i,PP}-v_i) \times \left(\frac{\partial w(n,p,B,o^*_{i,PP})}{\partial o^*_{i,PP}} \times \frac{1}{w(n,p,B,o_{i,PP^*})}\right) \tag{1.25}$$

Equation (1.25) implies that either $o^*_{i,PP} = v_i$ or $\frac{\partial w(n,p,B,o^*_{i,PP})}{\partial o^*_{i,PP}} = 0$. Given that $o^*_{i,TC} = v_i$ only when $v_i = 1$, the two optimal offer functions can be the same only when each participant cannot affect the probability the provision point requirement is met by changing their offer or $v_i = 1$.

To prove the other direction, suppose that no individual can affect the probability that the provision point requirement is met by changing their offer. Then, by definition, $\dfrac{\partial w(n,p,B,o^*_{i,PP})}{\partial o^*_{i,PP}} = 0$ and, using (1.21)

$$(o^*_{i,PP} - v_i) = \frac{-g(n,p,o^*_{i,PP}) \times w(n,p,B,o^*_{i,PP})}{\left(\dfrac{\partial g(n,p,o^*_{i,PP})}{\partial o^*_{i,PP}} \times w(n,p,B,o^*_{i,PP}) + 0 * g(n,p,o^*_{i,PP})\right)} \tag{1.26}$$

Simplifying (1.26) provides

$$(o^*_{i,PP} - v_i) = \frac{-g(n,p,o^*_{i,PP})}{\left(\dfrac{\partial g(n,p,o^*_{i,PP})}{\partial o^*_{i,PP}}\right)} \tag{1.27}$$

which is the first order condition for the multiunit reverse discriminative auction. If instead of assuming that no individual can affect the probability the provision point requirement is met we assume that $v_i = 1$, the result follows immediately from Axiom 1. □

This proposition provides our first theoretical prediction: when the parameters of a PPRA are such that no single participant can affect the probability that the provision point requirement is met, the optimal offer function for all participants in the auction is the optimal offer function for a multiunit reverse discriminative auction. Proposition 4 expands upon Proposition 3.

Proposition 4. *Suppose $O^*_{i,TC}(v_i)$ is the symmetric Bayesian Nash equilibrium optimal offer function for the multiunit reverse discriminative auction with a target of $p < n$ and $O^*_{i,PP}(v_i)$ is a symmetric Bayesian Nash equilibrium optimal offer function for the provision point reverse auction with a provision point requirement of $p < n$ and a budget of B. Further suppose that $O^*_{i,TC}(v_i)$ is convex in v_i.*[2] *If a participant in the auction can impact the probability that the provision point requirement is met, then $O^*_{i,TC}(v_i) > O^*_{i,PP}(v_i)$ for all v_i.*

[2]The convexity assumption holds for every set of parameter values I have tested.

Proof. Equations (1.20) and (1.21) provide the first order conditions for the optimal offer for an individual competing in a multiunit reverse discriminative auction and a provision point reverse auction, respectively. Note that $g(n,p,o_i^*)$ and $w(n,p,B,o_i^*)$ are decreasing and non-increasing in o_i^*, respectively, so that both $\frac{\partial g(n,p,o_{i,PP}^*)}{\partial o_{i,PP}^*}$ and $\frac{\partial w(n,p,B,o_{i,PP}^*)}{\partial o_{i,PP}^*}$ are less than or equal to zero. We prove by contradiction. Suppose that $o_{i,TC}^* \leq o_{i,PP}^*$. Then, combining (1.22) and (1.20), we have:

$$\frac{-1}{\left(\frac{\partial g(n,p,o_{i,PP}^*)}{\partial o_{i,PP}^*} \times \frac{1}{g(n,p,o_{i,PP}^*)} + \frac{\partial w(n,p,B,o_{i,PP}^*)}{\partial o_{i,PP}^*} \times \frac{1}{w(n,p,B,o_{i,PP^*})}\right)} > \frac{-g(n,p,o_{i,TC}^*)}{\left(\frac{\partial g(n,p,o_{i,TC}^*)}{\partial o_{i,TC}^*}\right)} \tag{1.28}$$

Note that both sides of the inequality are positive. Thus, multiplying both sides of the inequality by their reciprocal does not reverse the inequality. The resulting rearrangement is given by

$$-\left(\frac{\partial g(n,p,o_{i,TC}^*)}{\partial o_{i,TC}^*}\right) \times \frac{1}{g(n,p,o_{i,TC}^*)} > \left(-\frac{\partial g(n,p,o_{i,PP}^*)}{\partial o_{i,PP}^*} \times \frac{1}{g(n,p,o_{i,PP}^*)} - \frac{\partial w(n,p,B,o_{i,PP}^*)}{\partial o_{i,PP}^*} \times \frac{1}{w(n,p,B,o_{i,PP^*})}\right) \tag{1.29}$$

Given our assumptions about $w(n,p,B,o_{i,PP})$ and $g(n,p,o_{i,PP})$, we know that

$$-\frac{\partial w(n,p,B,o_{i,PP}^*)}{\partial o_{i,PP}^*} \times \frac{1}{w(n,p,B,o_{i,PP^*})} \geq 0 \tag{1.30}$$

and

$$-\frac{\partial g(n,p,o_{i,PP}^*)}{\partial o_{i,PP}^*} \times \frac{1}{g(n,p,o_{i,PP}^*)} \geq 0 \tag{1.31}$$

Returning to (1.29), if the sum of (1.30) and (1.31) is less than the left-hand side of (1.29), then we know that (1.31) is also less than the left-hand side of (1.29).

$$-\frac{\partial g(n,p,o_{i,PP}^*)}{\partial o_{i,PP}^*} \times \frac{1}{g(n,p,o_{i,PP}^*)} < -\left(\frac{\partial g(n,p,o_{i,TC}^*)}{\partial o_{i,TC}^*}\right) \times \frac{1}{g(n,p,o_{i,TC}^*)} \tag{1.32}$$

which further implies that

$$-\frac{g(n,p,o^*_{i,PP})}{\left(\frac{\partial g(n,p,o^*_{i,PP})}{\partial o^*_{i,PP}}\right)} > -\frac{g(n,p,o^*_{i,TC})}{\left(\frac{\partial g(n,p,o^*_{i,TC})}{\partial o^*_{i,TC}}\right)} \tag{1.33}$$

The completion of this proof requires a lemma.

Lemma 1. *Suppose $O^*_{i,TC}(v_i)$ is the symmetric Bayesian Nash equilibrium optimal offer function for the multiunit reverse discriminative auction with a target of $p < n$. Additionally, suppose that $O^*_{i,TC}(v_i)$ is a convex function. Then the difference between a given optimal offer, $o^*_{i,TC}$, and its corresponding value, v_i, is a decreasing function in v_i.*

Proof. Equation (1.20) provides the first order condition for the optimal offer, given a value v_i, in a multiunit reverse discriminative auction. The left-hand side of (1.20) provides the difference between an optimal offer and its corresponding value. Taking a derivative with respect to v_i on both sides yields

$$\frac{\partial O^*_{i,TC}(v_i)}{\partial v_i} - 1 = \partial\left(\frac{-g(n,p,o^*_{i,TC})}{\left(\frac{\partial g(n,p,o^*_{i,TC})}{\partial o^*_{i,TC}}\right)}\right)/\partial v_i \tag{1.34}$$

Proposition 2 states that $O^*_{i,TC}(v_i)$ is an increasing function, and the convexity assumption implies that the second derivative of $O^*_{i,TC}(v_i)$ is positive over the range [0,1) as well. If $\frac{\partial O^*_{i,TC}(v_i)}{\partial v_i}$ was greater than 1 for any v_i in this range, then $\frac{\partial O^*_{i,TC}(v_j)}{\partial v_i}$ would also have to be greater than 1, for any $v_j > v_i$, by convexity. Recall that $O^*_{i,TC}(v_i)$ is bounded below by the 45 degree line and that $O^*_{i,TC}(v_i)$ converges to 1 as v_i converges to 1, by Proposition 1. If the derivative of $O^*_{i,TC}(v_i)$ was ever greater than 1, then $O^*_{i,TC}(v_i)$ would not converge to 1 as v_i converged to 1. Thus, $\frac{\partial O^*_{i,TC}(v_i)}{\partial v_i}$ can never be greater than 1. This fact, along with Equation 1.34, immediately provides the desired result. □

Lemma 1 states that

$$\partial \left(\frac{-g(n,p,o^*_{i,TC})}{\left(\frac{\partial g(n,p,o^*_{i,TC})}{\partial o^*_{i,TC}}\right)} \right) / \partial v_i < 0 \tag{1.35}$$

The only avenue through which v_i affects $-\dfrac{g(n,p,o^*_{i,PP})}{\left(\dfrac{\partial g(n,p,o^*_{i,PP})}{\partial o^*_{i,PP}}\right)}$ is o_i. Further, because o_i is an increasing function of v_i, we have

$$\partial \left(\frac{-g(n,p,o^*_{i,TC})}{\left(\frac{\partial g(n,p,o^*_{i,TC})}{\partial o^*_{i,TC}}\right)} \right) / \partial o_i < 0 \tag{1.36}$$

Inequality (1.36), along with the assumption that $o^*_{i,PP} > o^*_{i,TC}$, implies that (1.33) is a contradiction. □

Propositions 3 and 4 tell us that we expect the optimal offer curve for the PPRA to be weakly below the optimal offer curve for a multiunit reverse discriminative auction with the same parameter values. The degree to which the optimal offer curve for the PPRA lies below the optimal offer curve for the multiunit reverse discriminative auction depends on the parameter values chosen. Note that these propositions do not make assumptions about the uniqueness of the symmetric Bayesian Nash equilibrium for the provision point reverse auction, but they do state that any symmetric Bayesian Nash equilibria for the PPRA must be less than the symmetric Bayesian Nash equilibrium for the target-constrained auction.

1.5 Experimental Design and Protocol

To test the theoretical predictions, ten experimental sessions were conducted with a total of 240 undergraduate student participants in Cornell University's Lab for

Experimental Economics and Decision Research (LEEDR). [3] Informed consent was obtained from all participants, in accordance with IRB regulations. The ten sessions were divided into five treatments of two sessions each. The five treatments consisted of one "budget-constrained" multiunit reverse discriminative treatment with a budget of $4.42, two "target-constrained" multiunit reverse discriminative treatments with targets of five and three, and two provision point treatments with a budget of $4.42, one with a provision point requirement of five and the other with a provision point requirement of three. For clarity and to ease comparisons between treatments, this paper will, from this point on, refer to multiunit reverse discriminative auctions as "target-constrained" auctions and multiunit reverse discriminative auctions with budgets as "budget-constrained" auctions. Each session lasted at most 40 minutes. Student participants were not allowed to participate in more than one session, and each session conducted auctions for only one of the treatments. Thus, all of the following analysis is between-subjects, rather than within-subjects. Average earnings were approximately $24 for each participant, with a range from $12 to $35. In each session, the 24 students were split evenly into three groups. Before the start of each session, the participants were given written instructions, which are included in the appendix. These written instructions include the following information:

1. The number of participants in a group (8).
2. The target or provision point requirement (5 or 3), if relevant.
3. The budget ($4.42), if relevant.

[3]For the auction to function, 24 undergraduates were required for each session. To increase the probability of 24 students attending the experiment, 32 students were recruited each session. Overbooked students were given $10 and allowed to sign up for the experiment during a different time. On two occasions, less than 24 students showed up for the experiment. These sessions were cancelled, and the students who showed up were given $10 and allowed to sign up for a different session in the future.

4. The common distribution from which all opportunity costs were drawn, U(0,2).[4]

A group size of 8 was chosen because relatively small group sizes increased both the sample and the impact of the provision point requirement. For the first PPRA treatment a provision point requirement of $p = 5$ was chosen so that a relatively large number of participants could contribute to the provision point requirement, while a target of 6 or 7 individuals might have led to larger offers in the target-constrained auction. In addition, initial parameters were chosen so that the participants in the auction could not divide the budget equally among themselves. That is, the budget was selected so that the fifth highest opportunity cost in each group was larger than the budget divided by 5. If at least one of the five lowest opportunity costs is greater than the budget divided by the provision point requirement, I say the auction is "psychologically binding." To test the robustness of the mechanism, these sessions were followed with an additional PPRA treatment but with a provision point requirement of 3 rather than 5. This second PPRA treatment was not psychologically binding, as the budget divided by 3 was larger than the third highest opportunity cost in all groups.

For the purpose of common knowledge, the author read from a series of PowerPoint slides which included an overview of the experimental instructions. After the PowerPoint presentation, all subjects participated in 5 practice rounds where parameter values varied. The practice rounds allowed participants to test offering

[4] Note that individuals drew offers from a U(0,2) distribution rather than a U(0,1), as we assumed in the theory section. This decision was made after conducting a pilot experiment where individuals drew costs up to \$1. I found that, with such low opportunity costs, the individual rounds were not salient to the participants. Indeed, the participants became increasingly impatient as the session continued. As a result, I reduced the number of rounds to 16 and increased the maximum opportunity cost to \$2. Because the assumed distribution is uniform, this does not impact theoretical predictions made in propositions 3 and 4.

strategies without having to worry about affecting their earnings. The practice rounds also increased the participants familiarity with their mechanism by altering the parameter values between rounds. The auctions were programmed using Microsoft Excel. In each round, the participants selected an offer between \$0 and \$7, where \$7 was set as the maximum allowable offer. After each round, the participants were informed whether their offer was accepted and how much they were paid. If they were in the provision point reverse auction treatment, they were also informed if the provision point requirement was met. After the five practice rounds, opportunity costs were re-randomized and a series of 8 rounds began where the budget, target, provision point requirement and opportunity costs for each individual were fixed. Before the 9th round, the groups and opportunity costs were randomized once more and another 8 rounds were conducted to end the experiment. Participants were not paid for the practice rounds, but were paid based on the results of all 16 rounds that followed.

Figure 1.2 provides gives an example of the interface used by the participants of a provision point reverse auction. In this example, an individual is preparing to submit an offer in Round 8. This individual has submitted a variety of offers in Rounds 1-7, but never received a contract, despite the fact that the provision point requirement was met in Rounds 1, 3, 4, and 7. This indicates that there were at least five smaller offers in those rounds. When an individual is ready to submit an offer, they type their offer into the yellow box and hit the “submit” button. This sends their offer to the researcher. Once all of 24 participants have submitted their offers, the researcher resolves the auction and sends the results of the auction back to the participants. Participants can then hit the “Update” button, which updates their interface with the results of the previous round and advances them to the next round.

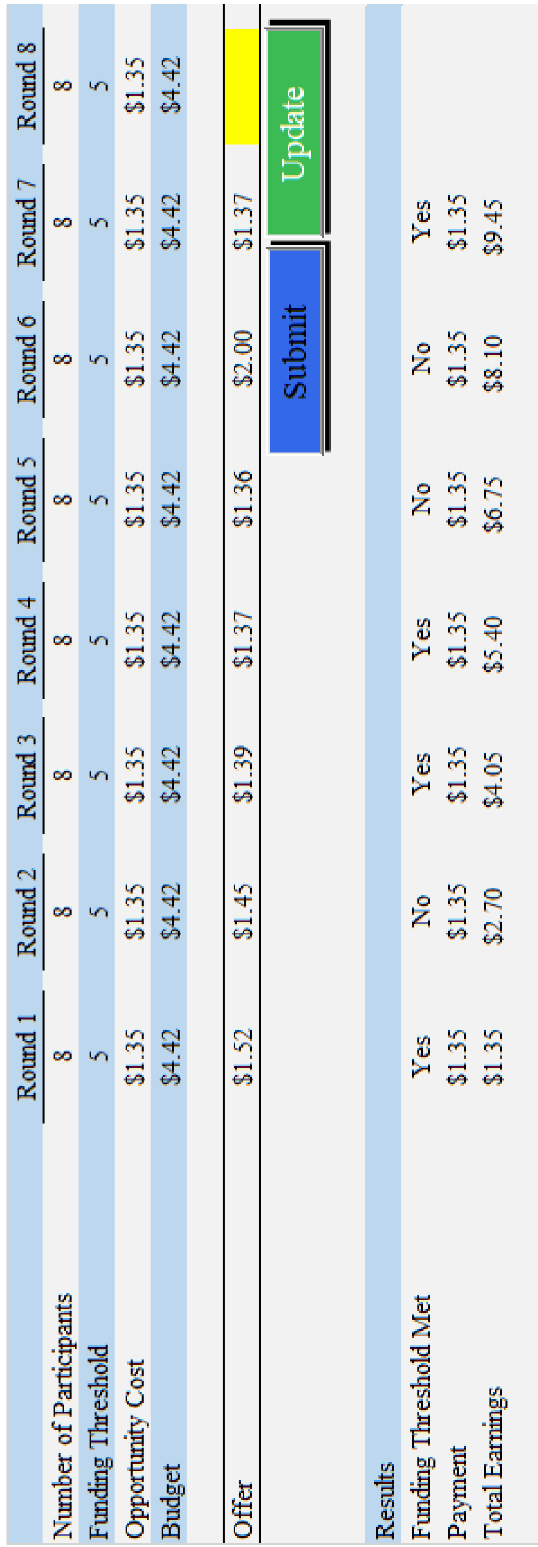
Figure 1.3 provides the interface for an individual at the end of a target-constrained auction. The individual received contracts in Rounds 11 and 12. For the entire session, the individual earned \$12.88, not including show-up fee. Note that this interface does not include any information about budgets or funding thresholds, as the target-constrained auction format does not include either element. The budget-constrained interface is similar to the target-constrained interface, but with a "Budget" row instead of a "Funding Threshold" row.

1.6 Results

1.6.1 Difference in Means

The first comparison between auction formats is a simple unconditional difference in means test between treatments and within rounds. An unconditional difference in means test is appropriate because the opportunity costs for the participants were randomized before the experimental sessions and were identical across treatments. The experimental format provides two sets of 8 rounds which are pooled to increase statistical power. That is, the offers from Rounds 1 and 9 are considered jointly, the offers from Rounds 2 and 10 are considered jointly, and so on. Given the varying parameter values, average offers were compared between formats with comparable restrictions. That is, the target-constrained auction with a target of 5, the budget-constrained auction with a budget of \$4.42, and the PPRA with a provision point requirement of 5 and a budget of \$4.42 were compared, and then the target-constrained auction with a target of 3, the budget-constrained auction with a budget = \$4.42, and the PPRA with a provision point requirement of 3

Figure 1.2: Experiment Interface: Provision Point Reverse Auction



	Round 1	Round 2	Round 3	Round 4	Round 5	Round 6	Round 7	Round 8
Number of Participants	8	8	8	8	8	8	8	8
Funding Threshold	5	5	5	5	5	5	5	5
Opportunity Cost	$1.35	$1.35	$1.35	$1.35	$1.35	$1.35	$1.35	$1.35
Budget	$4.42	$4.42	$4.42	$4.42	$4.42	$4.42	$4.42	$4.42
Offer	$1.52	$1.45	$1.39	$1.37	$1.36	$2.00	$1.37	
Results								
Funding Threshold Met	Yes	No	Yes	Yes	No	No	Yes	
Payment	$1.35	$1.35	$1.35	$1.35	$1.35	$1.35	$1.35	
Total Earnings	$1.35	$2.70	$4.05	$5.40	$6.75	$8.10	$9.45	

and a budget of \$4.42 were compared. The results are given in Table 1.1 and 1.2 below. For each set of pooled rounds, every treatment has 96 observations. Thus, each unconditional difference in means test has 192 total observations.

In each table, columns (1), (2) and (3) provide the mean offers for each treatment in each set of rounds, while columns (4) and (5) provide the difference in means between the treatments and the PPRA. There are several important results in Table 1.1. First, the target-constrained treatment has higher average offers than either of the other two treatments. Indeed, the difference in means between the the provision point reverse auction and the target-constrained treatment is above \$1 in most rounds. The theory predicted that average offers would be higher in the target-constrained auction than the provision point reverse auction, but the magnitude of the differences was unexpected. Second, the budget-constrained treatment has higher average offers than the PPRA as well, albeit to a lesser extent. In most rounds, the budget-constrained treatment has offers more than \$0.20 higher than its provision point counterpart. Third, notice that while the average offers are relatively stable across rounds for the PPRA and budget-constrained auction, the target-constrained auction saw its average offers decrease over time. This runs contrary to previously established theoretical results, which suggest offers increase over time in a target-constrained auction. Instead, it seems individuals submitted high offers in the first round, and their offers decreased over time as the participants competed over contracts. This may be a result of the relatively small group size, as conversation (and therefore collusion) between individuals was not permitted during the experiment. The statistically significant differences in means support the claim that the PPRA can reduce offers when compared to the target- or budget-constrained treatments.

Figure 1.3: Experiment Interface: Target-Constrained Auction

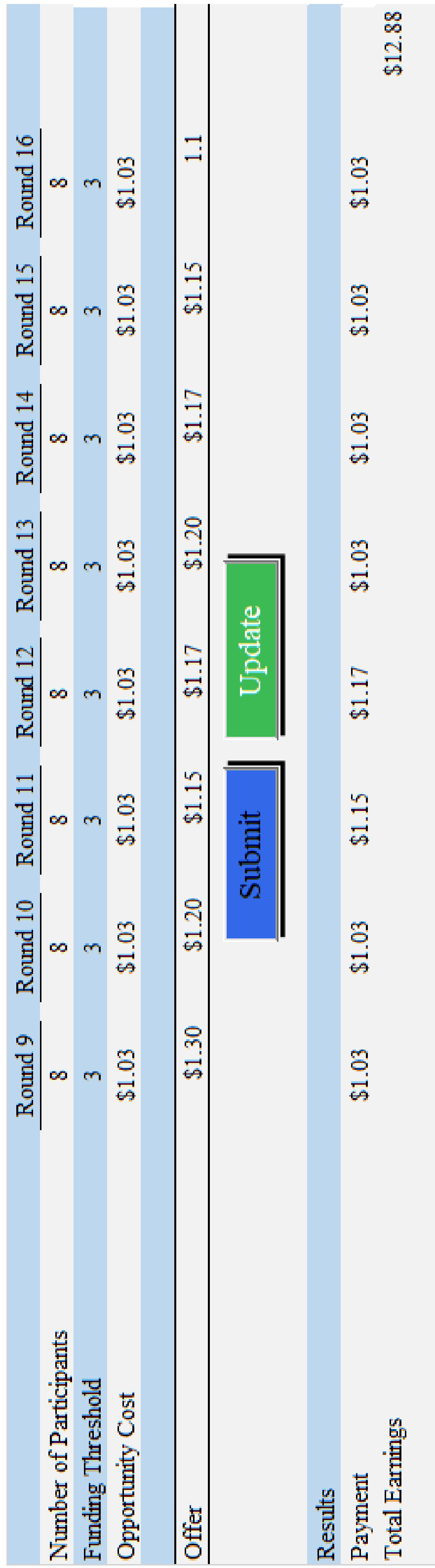


Table 1.1: Mean Offers – Target = 5, Budget = \$4.42, PPR = 5

	Mean Offers			Difference: PPRA &	
	(PPRA)	(TC)	(BC)	TC	BC
Rounds	(1)	(2)	(3)	(4)	(5)
1 & 9	1.124	2.716	1.383	1.593***	0.259***
	(0.450)	(1.105)	(0.687)	(0.123)	(0.086)
2 & 10	1.115	2.440	1.401	1.324***	0.285***
	(0.487)	(0.740)	(0.670)	(0.090)	(0.085)
3 & 11	1.143	2.389	1.372	1.246***	0.228***
	(0.498)	(0.644)	(0.620)	(0.083)	(0.081)
4 & 12	1.145	2.257	1.420	1.111***	0.274***
	(0.490)	(0.501)	(0.859)	(0.071)	(0.101)
5 & 13	1.137	2.223	1.347	1.086***	0.209***
	(0.464)	(0.430)	(0.529)	(0.065)	(0.072)
6 & 14	1.200	2.161	1.335	0.961***	0.135*
	(0.577)	(0.371)	(0.508)	(0.070)	(0.078)
7 & 15	1.167	2.090	1.360	0.923***	0.193**
	(0.475)	(0.328)	(0.550)	(0.059)	(0.074)
8 & 16	1.186	2.101	1.364	0.915***	0.178**
	(0.576)	(0.604)	(0.587)	(0.085)	(0.084)
All	1.152	2.297	1.373	1.115***	0.220***
	(0.507)	(0.662)	(0.633)	(0.030)	(0.029)

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Note: The above table contains the mean for each of the three auction treatments and difference in means between the TC and BC auction treatments and the PPRA, with the standard deviations and standard errors below for the means or differences in means, respectively. Each t-test is conducted with a sample of 96 for each treatment: 24 observations for each Round, with a total of 48 after the rounds are pooled, and two sessions for each treatment. PPRA denotes the provision point reverse auction, TC denotes the target-constrained auction and BC denotes the budget-constrained auction. The results above are for target-constrained auctions with a target of 5, a budget-constrained auction with a budget of \$4.42 and a provision point reverse auction with a provision point requirement of 5 and a budget of \$4.42. The offers were pooled by rounds, so that the offers from rounds 1 and 9 were considered jointly, the offers from rounds 2 and 10 were considered jointly, etc.

Table 1.2: Mean Offers – Target = 3, Budget = \$4.42, PPR = 3

	Mean Offers			Difference: PPRA &	
	(PPRA)	(TC)	(BC)	TC	BC
Rounds	(1)	(2)	(3)	(4)	(5)
1 & 9	1.249	1.631	1.383	0.382***	0.134
	(0.628)	(0.556)	(0.687)	(0.086)	(0.095)
2 & 10	1.197	1.454	1.401	0.257***	0.203**
	(0.561)	(0.407)	(0.670)	(0.071)	(0.089)
3 & 11	1.252	1.409	1.372	0.157**	0.120
	(0.639)	(0.381)	(0.620)	(0.076)	(0.091)
4 & 12	1.269	1.400	1.420	0.131	0.151
	(0.672)	(0.457)	(0.859)	(0.083)	(0.111)
5 & 13	1.239	1.362	1.347	0.123	0.108
	(0.636)	(0.481)	(0.529)	(0.081)	(0.084)
6 & 14	1.225	1.361	1.335	0.137	0.111
	(0.601)	(0.695)	(0.508)	(0.094)	(0.080)
7 & 15	1.319	1.339	1.360	0.021	0.041
	(0.766)	(0.584)	(0.550)	(0.098)	(0.096)
8 & 16	1.323	1.412	1.364	0.089	0.041
	(0.922)	(0.785)	(0.587)	(0.124)	(0.112)
All	1.259	1.421	1.373	0.162***	0.114***
	(0.685)	(0.563)	(0.633)	(0.032)	(0.034)

*** p<0.01, ** p<0.05, * p<0.1

Note: The above table contains the mean for each of the three auction treatments and difference in means between the TC and BC auction treatments and the PPRA, with the standard deviations and standard errors below for the means or differences in means, respectively. Each t-test is conducted with a sample of 96 for each treatment: 24 observations for each Round, with a total of 48 after the rounds are pooled, and two sessions for each treatment. PPRA denotes the provision point reverse auction, TC denotes the target-constrained auction and BC denotes the budget-constrained auction. The results above are for target-constrained auctions with a target of 3, a budget-constrained auction with a budget of \$4.42 and a provision point reverse auction with a provision point requirement of 3 and a budget of \$4.42. The offers were pooled by rounds, so that the offers from rounds 1 and 9 were considered jointly, the offers from rounds 2 and 10 were considered jointly, etc.

Table 1.2 provides the results from additional experiments with different parameter values, where both the target-constraint and the provision point requirement were set to 3. First, note that average offers are always less in the PPRA than either the target- or budget-constrained auction, but that the differences are not statistically significant in most rounds. This agrees with our intuitive expectations, where a smaller target with a constant budget is less restrictive than a larger target with the same budget. Indeed, these results are generally consistent with the contention that, even when the provision point requirement is not more restrictive than the target or budget constraint, the provision point auction provides lower average offers. Also note that, with these parameter values, the target- and budget-constrained auctions provide more comparable average offers than seen in Table 1.1, where the target-constrained auction resulted in substantially higher offers.

Tables 1.1 and 1.2 provide differences in means across all offers. The buyer, however, is primarily interested in the lowest p offers because those offers actually receive contracts and result in payments from the buyer. Thus, a comparison of means of the lowest p offers between auction formats would provide more information about improvements in the buyer's welfare than a comparison of all offers. The difference in means for the lowest five offers between the target-constrained treatment with a target of five, the budget-constrained treatment with a budget of \$4.42, and the PPRA with a budget of \$4.42 and provision point requirement of five are given in Table 1.3. Table 1.3 shows comparable differences to Table 1.1 and provides additional support that the PPRA may be an attractive alternative to the target- and budget-constrained auctions from the perspective of the buyer. Indeed, the mean of the five lowest offers in a PPRA was between 19.4% and 25.6% smaller in the tested provision point reverse auctions than the comparable budget-constrained auction, depending on the round. One advantage of comparing the lower offers is that large outliers are removed from the comparison. For each set of pooled rounds in Table 1.3, every treatment has 60 observations. Thus, each unconditional difference in means test has 120 total observations.

The difference in means for the lowest three offers between the target-constrained treatment with a target of three, the budget-constrained treatment with a budget of \$4.42, and the PPRA with a budget of \$4.42 and provision point requirement of three are given in Table 1.4. Table 1.4 shows statistically significant differences in means between the three auction formats in most rounds, and thus suggests that the PPRA can yield improvements in the buyer's welfare for an additional set of parameter values. More specifically, the mean of the three lowest offers in tested provision point auctions was between 8.9% and 15.7% smaller than the comparable mean in the budget-constrained auctions, depending on the rounds. Indeed, Table 1.4 provides more compelling evidence than Table 1.2 that the PPRA can lower offers, even when the provision point requirement isn't "psychologically binding." For each set of pooled rounds in Table 1.4, every treatment has 36 observations. Thus, each unconditional difference in means test has 72 total observations. This provides substantially less power than the tests shown in Tables 1.1 and 1.2. However, significant differences in offers between the PPRA and target-constrained auction remain in all pooled rounds. Significant differences in offers between the PPRA and budget-constrained auctions remain in most of the pooled rounds as well.

Table 1.3: Mean Lowest 5 Offers – Pooled Rounds

	Mean Offers			Difference: PPRA &	
	PPRA	TC	BC	TC	BC
Rounds	(1)	(2)	(3)	(4)	(5)
1 & 9	0.822	2.160	1.042	1.339***	0.220***
	(0.316)	(0.765)	(0.394)	(0.107)	(0.065)
2 & 10	0.814	2.069	1.093	1.255***	0.280***
	(0.292)	(0.608)	(0.320)	(0.087)	(0.056)
3 & 12	0.838	2.104	1.095	1.266***	0.256***
	(0.323)	(0.495)	(0.307)	(0.076)	(0.058)
4 & 12	0.848	2.027	1.070	1.179***	0.222***
	(0.323)	(0.397)	(0.306)	(0.066)	(0.057)
5 & 13	0.854	2.025	1.089	1.171***	0.235***
	(0.299)	(0.352)	(0.246)	(0.060)	(0.050)
6 & 14	0.885	2.016	1.103	1.131***	0.218***
	(0.307)	(0.333)	(0.223)	(0.058)	(0.049)
7 & 15	0.886	1.962	1.099	1.076***	0.213***
	(0.325)	(0.281)	(0.223)	(0.055)	(0.051)
8 & 16	0.870	1.934	1.094	1.064***	0.225***
	(0.310)	(0.298)	(0.224)	(0.056)	(0.049)
All	0.852	2.037	1.086	1.185***	0.234***
	(0.311)	(0.471)	(0.285)	(0.026)	(0.019)

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Note: The above table contains the mean of the lowest five offers for each of the three auction treatments and difference in means between the five lowest offers for the TC and BC auction treatments and the PPRA, with the standard deviations and standard errors below for the means or differences in means, respectively. Each t-test is conducted with a sample of 60 for each treatment: 15 observations for each Round, with a total of 30 after the rounds are pooled, and two sessions for each treatment. PPRA denotes the provision point reverse auction, TC denotes the target-constrained auction and BC denotes the budget-constrained auction. The results above are for target-constrained auctions with a target of 5, a budget-constrained auction with a budget of $4.42 and a provision point reverse auction with a provision point requirement of 5 and a budget of $4.42. The offers were pooled by rounds, so that the offers from rounds 1 and 9 were considered jointly, the offers from rounds 2 and 10 were considered jointly, etc.

Table 1.4: Mean Lowest 3 Offers – Pooled Rounds

	Mean Offers			Difference: PPRA &	
	PPRA	TC	BC	TC	BC
Rounds	(1)	(2)	(3)	(4)	(5)
1 & 9	0.750	1.142	0.823	0.392***	0.073
	(0.279)	(0.346)	(0.284)	(0.074)	(0.066)
2 & 10	0.777	1.094	0.922	0.317***	0.145**
	(0.268)	(0.257)	(0.253)	(0.062)	(0.061)
3 & 12	0.845	1.100	0.937	0.255***	0.092
	(0.237)	(0.248)	(0.266)	(0.057)	(0.059)
4 & 12	0.827	1.081	0.918	0.254***	0.091
	(0.241)	(0.224)	(0.269)	(0.055)	(0.060)
5 & 13	0.836	1.033	0.979	0.197***	0.143**
	(0.238)	(0.204)	(0.231)	(0.052)	(0.055)
6 & 14	0.864	1.010	0.995	0.176***	0.131***
	(0.211)	(0.219)	(0.190)	(0.051)	(0.047)
7 & 15	0.872	0.993	1.002	0.121**	0.130***
	(0.193)	(0.223)	(0.200)	(0.049)	(0.046)
8 & 16	0.849	0.992	0.998	0.143***	0.149***
	(0.206)	(0.200)	(0.207)	(0.048)	(0.049)
All	0.828	1.056	0.947	0.228***	0.119***
	(0.236)	(0.247)	(0.244)	(0.020)	(0.020)

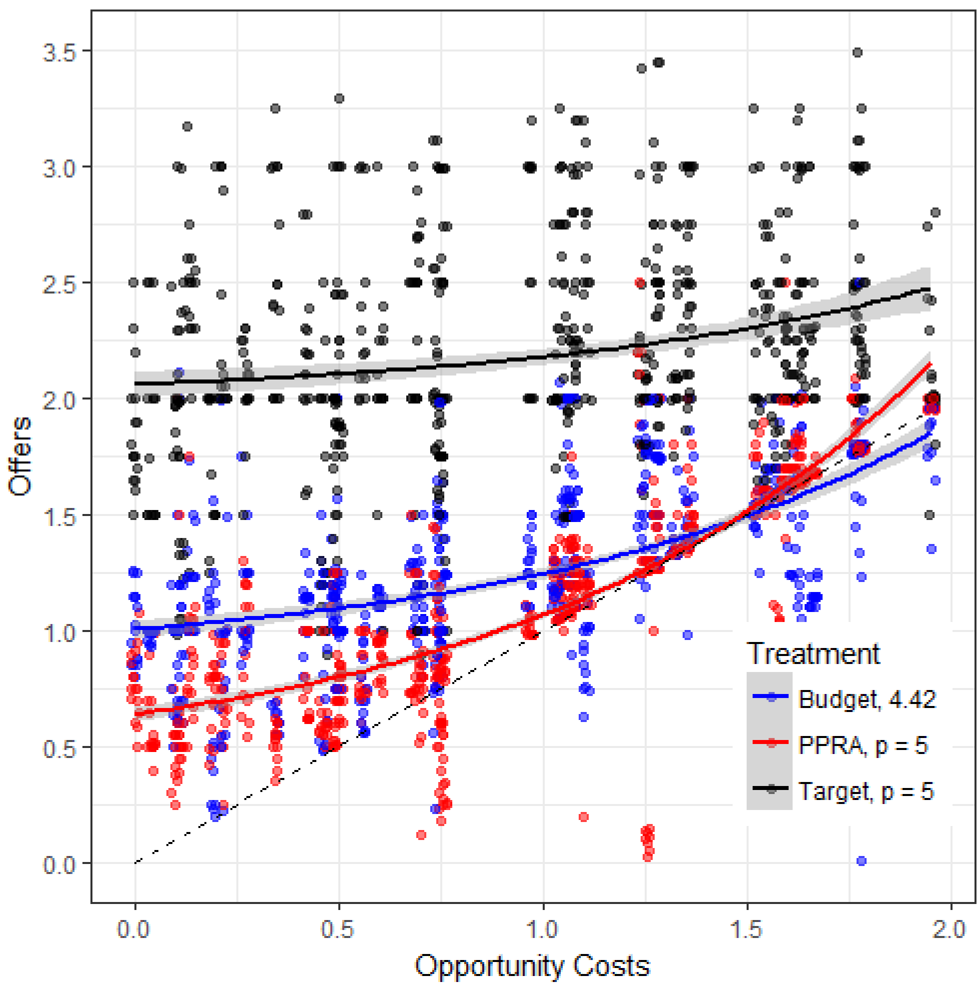
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Note: The above table contains the mean of the lowest three offers for each of the three auction treatments and difference in means between the three lowest offers for the TC and BC auction treatments and the PPRA, with the standard deviations and standard errors below for the means or differences in means, respectively. Each t-test is conducted with a sample of 36 for each treatment: 9 observations for each Round, with a total of 18 after the rounds are pooled, and two sessions for each treatment. PPRA denotes the provision point reverse auction, TC denotes the target-constrained auction and BC denotes the budget-constrained auction. The results above are for target-constrained auctions with a target of 3, a budget-constrained auction with a budget of \$4.42 and a provision point reverse auction with a provision point requirement of 3 and a budget of \$4.42. The offers were pooled by rounds, so that the offers from rounds 1 and 9 were considered jointly, the offers from rounds 2 and 10 were considered jointly, etc.

1.6.2 Offer Functions

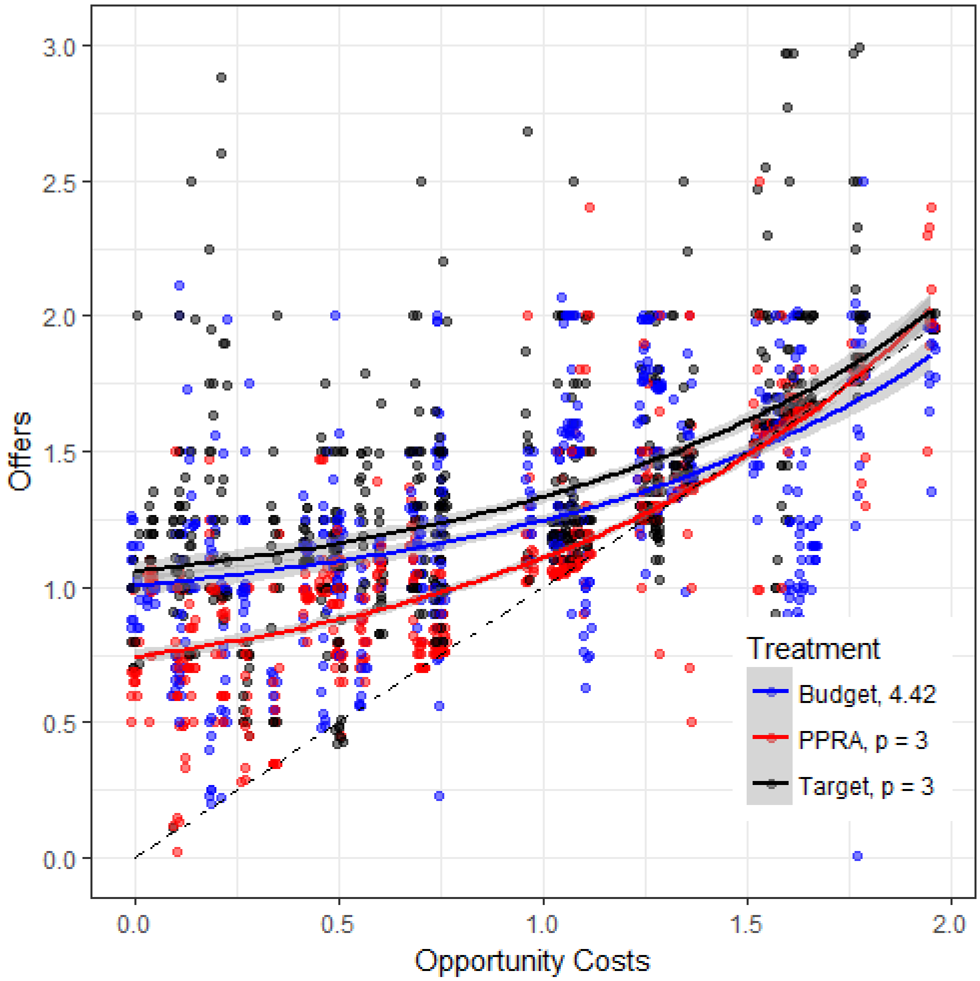
Figures 1.4 and 1.5 below display the fitted offer functions and individual offers (grouped by similar parameter values) observed from experiments across all rounds, assuming an exponential specification for the offer functions. The exponential specification was chosen both because of it's similarity to the optimal offer curve for the target-constrained auction (see Figure 1) and because it fits the data well, particularly compared to either a linear or quadratic specification.

Figure 1.4: Comparison of Offer Functions, PPR = 5: All Rounds



These figures show the degree to which individuals submitted offers above their

Figure 1.5: Comparison of Offer Functions, PPR = 3; All Rounds



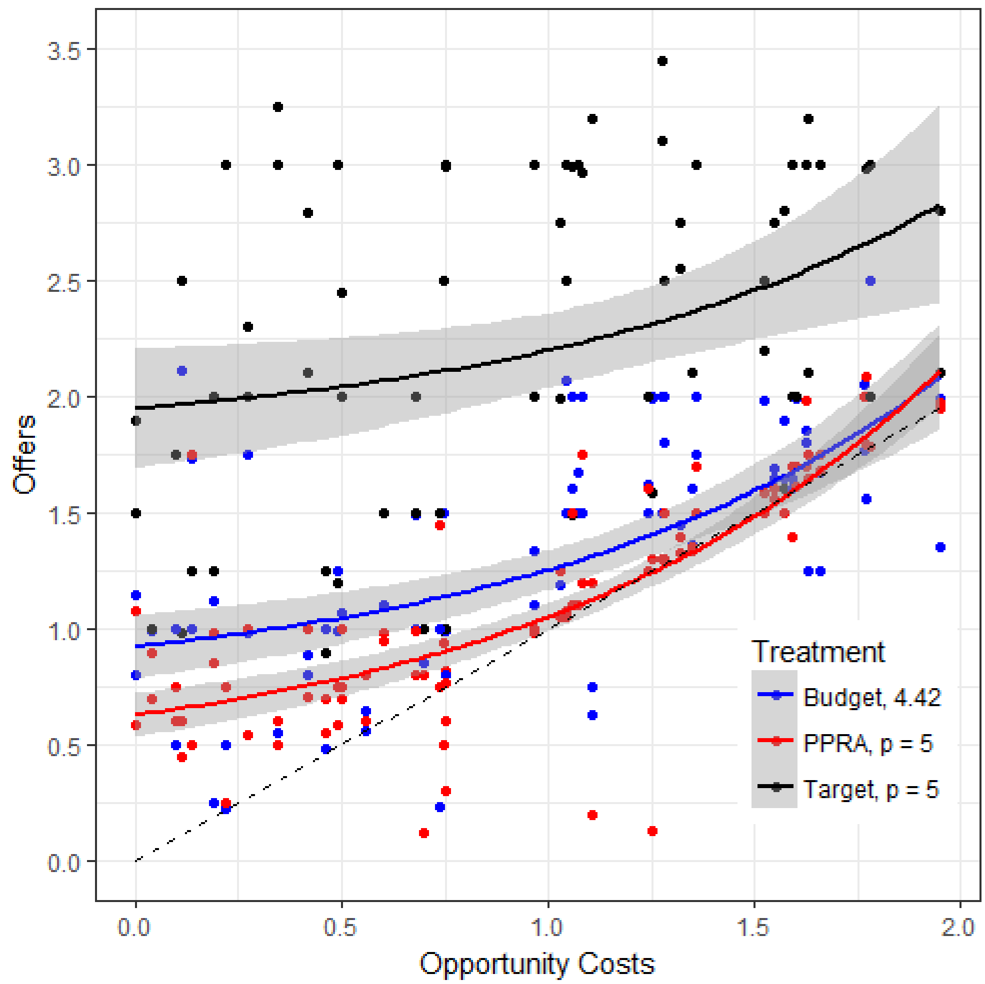
opportunity costs across the different treatments and for the different parameter values. In some instances, individuals submitted offers below their opportunity costs, represented by the 45 degree line. In a provision point reverse auction, it is possible that this behavior was altruistic: some individuals decreased their offers below their opportunity costs in the hope of satisfying the provision point requirement, and thus allowing some of their peers to receive profitable contracts. Why some individuals in the budget-constrained auction chose to submit offers below their opportunity cost is unclear, although the behavior was largely limited to a few participants. Each offer function is surrounded by a shaded region, representing a 95% confidence interval. Given the large variance in offers within treatments, I suggest greater consideration of the difference in average offers than the difference in coefficients on fitted functions. The variance in offers is consistent with individuals struggling to determine optimal offering behavior which is hardly surprising given the computational difficulty of determining an optimal offer for any of the three auction formats.

Figures 1.6 and 1.7 provide the offers and fitted offer curves for the first and ninth rounds and the eighth and sixteenth rounds, respectively, for the treatments with a target or provision point requirement of five and a budget of \$4.42, while Figures 1.8 and 1.9 provide similar representations of the data for treatments with a target or provision point requirement of 3 and a budget of \$4.42. The first and ninth rounds are the initial rounds after groups have been re-randomized, while the eighth and sixteenth rounds are the final rounds before either re-randomization or the conclusion of the experiment.

1.6.3 Efficiency Analysis

This paper is interested not only in comparing the three auction treatments with each other, but also against the theoretical predictions for the uniform reverse auction. In a uniform reverse auction, the buyer sets a target and the winning individuals receive the first rejected offer as payment, similar to a Vickrey second price auction. Theoretically, we expect individuals in a uniform procurement auction will submit their opportunity costs as their offers. To compare the auction formats this paper uses three criteria to measure their efficacy. The first measure

Figure 1.6: Comparison of Offer Functions, PPR = 5: First Rounds (1 & 9)

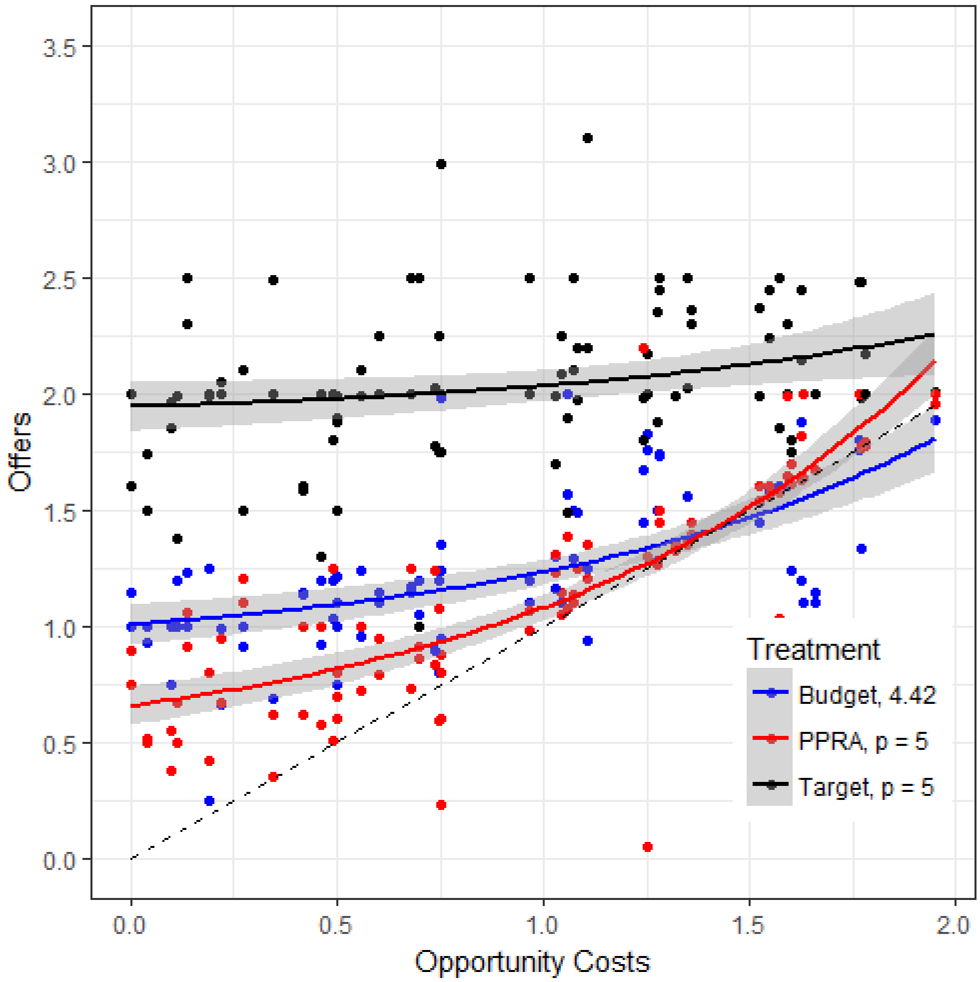


is social efficiency, which is defined as follows:

$$\text{Social Efficiency} = \frac{\sum_{i=1}^{p} v_{(i)}}{\sum_{i=1}^{p} v_i} \times 100 \tag{1.37}$$

where $v_{(i)}$ is the ith smallest opportunity cost in the auction. In other words, social efficiency is the minimum opportunity cost required to supply five contracts divided by the sum of the opportunity costs of the individuals who actually received contracts. From society's perspective, welfare is maximized when the lowest opportunity cost individuals receive the available contracts. However, this result is not necessarily the case in instances with positive externalities like one might

Figure 1.7: Comparison of Offer Functions, PPR = 5: Last Rounds (8 & 16)

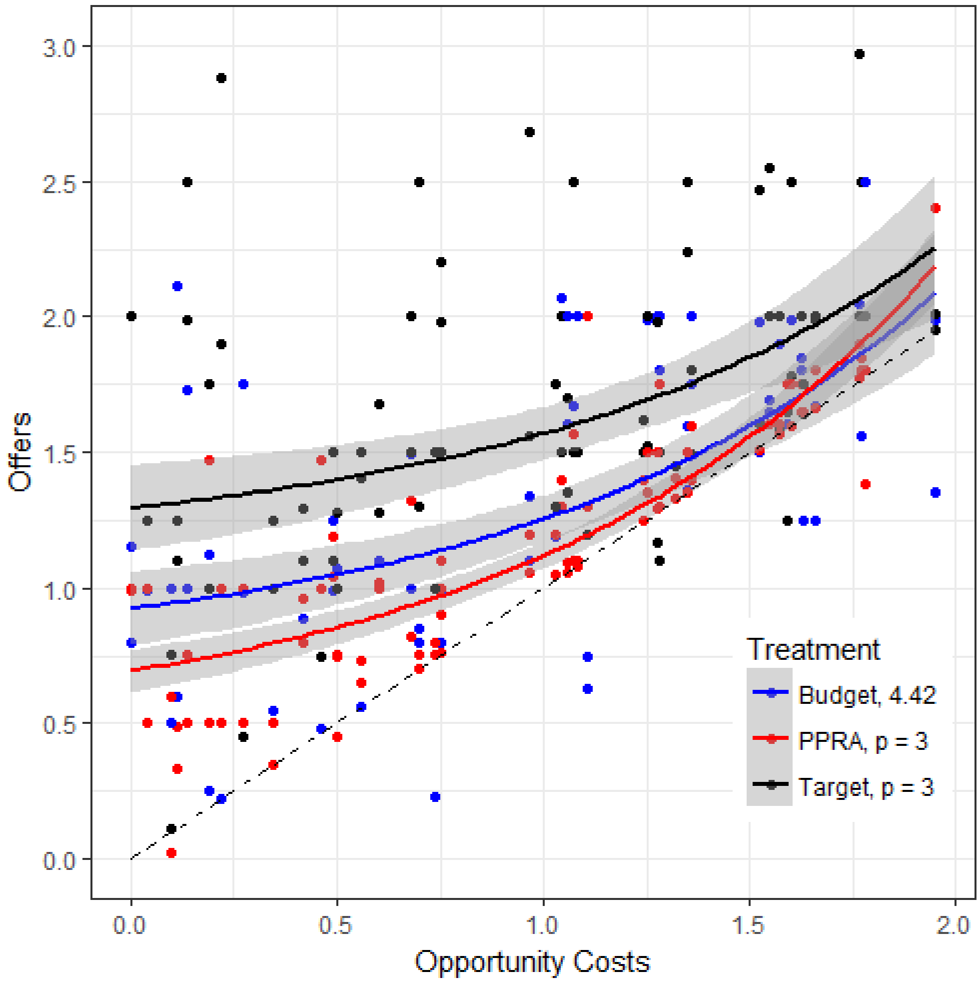


expect from PES programs. Nonetheless, the measure informative.

The second measure is simply the total cost to the buyer of purchasing p contracts. This allows us to compare cost savings for the buyer across the different auction mechanisms, and thus the amount of money the buyer must spend, on average, for the p units.

Finally, this paper uses a "cost effectiveness" measure to further compare how costly the auctions are for the buyer. This measure is defined as follows:

Figure 1.8: Comparison of Offer Functions, PPR = 3: First Rounds (1 & 9)

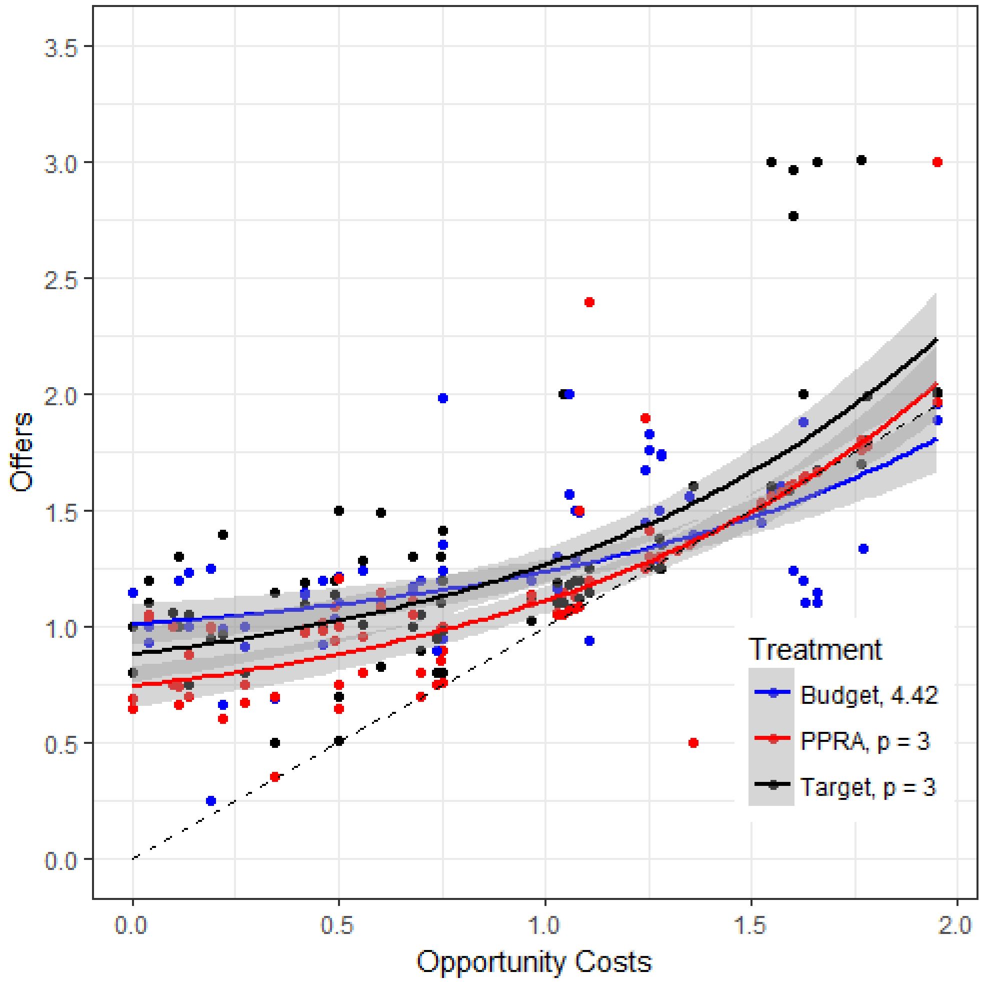


$$\text{Cost Effectiveness} = \frac{\text{Uniform Auction Cost} - \text{Other Auction Cost}}{\text{Uniform Auction Cost} - \text{Total Opportunity Cost}} \tag{1.38}$$

By definition, if the participants submitted offers equal to their opportunity costs, the cost efficiency measure would be 100%, while the cost efficiency measure is 0% for the uniform auction.

Tables 1.5 and 1.6 below provide the efficiency and cost effectiveness measures for the various auctions by their parameter values. The OC column provides the measures for a hypothetical discriminative auction where individuals submit their

Figure 1.9: Comparison of Offer Functions, PPR = 3: Last Rounds (8 & 16)



opportunity costs as offers. In such an auction, all of the welfare gains would be given to the buyer and the auction would be 100% socially efficient. As such, it serves as the ideal auction from the perspective of the buyer. There are two important problems to discuss before continuing to the efficiency measures. First, we cannot compare the budget-constrained auction to the other formats directly with these measures because the buyer, in the experiments, was never able to afford 5 contracts in the budget-constrained treatment. Thus, questions including, “how much did it cost the buyer to purchase five contracts” are nonsensical for budget-constrained auction. Second, the provision point auctions didn’t always result

Table 1.5: Efficiency Measures, Target/PPR = 5

	OC	Uniform	TC	PPRA
Social Efficiency	100%	100%	71.46% (14.89%)	95.98% (9.40%)
Avg. Total Cost of Providing 5 Units	\$3.02	\$6.64	\$10.19	\$4.07
Cost Effectiveness	100%	0%	-97.96% (29.65%)	71.12% (12.03%)

Note: The above table contains efficiency measures for several different auction formats. Standard errors are enclosed in parentheses below their given estimates. The OC column contains the results from a theoretical discriminative auction where all individuals submit their opportunity costs as offers. The Uniform column contains the predicted results from a uniform price auction. The TC column contains the experimental results for the target-constrained auction and the PPRA column contains the experimental results for the provision point reverse auction in rounds where the provision point requirement was met.

in contracts in the treatment with PPR = 5, as the provision point requirement wasn't met in approximately 33% of the rounds. (The PPR was met in every round for the treatment with PPR = 3.) As a result, it isn't always sensible to compare the PPRA to the target-constrained and uniform price auctions. Instead, this paper presents only the efficiency measure for the PPRA when the provision point requirement was met. This alters the efficiency estimates slightly when the PPR = 5, but does not alter the analysis when the PPR = 3.

Unsurprisingly, given the theoretical predictions, the target-constrained auction performs the worst by all three measures, regardless of the parameter values. Indeed, the target-constrained auction costs over twice as much, on average, as the provision point reverse auction and costs nearly 80% more than the predictions for the uniform auction as well, when $p = 5$. On the other hand, the provision point reverse auction was only slightly less socially efficient than the predictions for the uniform auction when $p = 5$, although the PPRA achieved lower social efficiency

Table 1.6: Efficiency Measures, Target/PPR = 3

	OC	Uniform	TC	PPRA
Social Efficiency	100%	100%	64.61% (24.65%)	76.8% (22.85%)
Avg. Total Cost of Providing 3 Units	\$1.06	\$2.64	\$3.17	\$2.48
Cost Effectiveness	100%	0%	-33.82% (34.21%)	9.66% (35.92%)

Note: The above table contains efficiency measures for several different auction formats. Standard errors are enclosed in parentheses below their given estimates. The OC column contains the results from a theoretical discriminative auction where all individuals submit their opportunity costs as offers. The Uniform column contains the predicted results from a uniform price auction. The TC column contains the experimental results for the target-constrained auction and the PPRA column contains the experimental results for the provision point reverse auction in rounds where the provision point requirement was met.

than the predictions for the uniform price auction when $p = 3$. In summary, the PPRA performs better than the uniform price auction from the perspective of the buyer, while it performs slightly worse than the uniform price auction by social efficiency. However, the difference in the social efficiency measure is not statistically significant for the session where the provision point requirement was equal to 5.

1.7 Discussion

Given the structure of the PPRA, I believe it will be particularly effective when three criteria hold true. First, if there is a threshold of interest the PPRA can ensure the government either some level of environmental service or the welfare they obtain from retaining their budget and expending it on an alternative PES program.

Second, I believe that the PPRA will be particularly effective for auctions with small numbers of participants who all operate in a given region. As the number of participants in a PPRA becomes smaller, the ability of any individual to affect the probability the provision point requirement is met increases, which increases the impact of the provision point requirement on offering behavior (See Propositions 3 and 4). Further, I believe that individuals who know each other will be more likely to take the welfare of the other participants into account. As such, a PPRA which takes place in a particular region may increase the salience of the provision point requirement even further.

Finally, the PPRA will be most effective at reducing offers when the cost of running an auction is low and when the buyer can move the program to a new location when the provision point requirement isn't met. The buyer may forgo substantial welfare opportunities if they cannot eventually provide contracts to some individuals, and thus the ability to move the auction to a new location at relatively little cost will decrease the chance the buyer will not able to purchase some environmental service.

As an example of a setting which satisfies these three criteria, consider the BirdReturn© program in California. In the BirdReturn© program, rice farmers in the Central Valley of California are paid by conservationists and aviphiles to flood their paddies to create small habitats for migratory birds. The number of rice farmers in a given area is relatively small, and if a certain number of these "pop-up habitats" are not created, then the birds will not be able to use the regions as stepping stones along their journey. There are several potential areas in the Central Valley that could serve as pop-up habitats, so the conservationists and aviphiles could move to a new location if they cannot afford a certain number of contracts.

While the provision point reverse auction has the potential to function well in some settings, it certainly would not be appropriate for all procurement auctions. For example, electricity markets use reverse auctions to allocate contracts to energy producers. A PPRA in this context would mean that no electricity would be produced when the provision point requirement is not met, which would be an unacceptable outcome given that demand for electricity is inelastic.

1.8 Conclusion

This paper introduces a new auction mechanism designed for conservation and PES settings. The Provision Point Reverse Auction uses co-dependent expected profit functions for the individuals seeking to provide environmental services to decrease rent-seeking behavior. This decrease in strategic behavior has the potential to increase the efficiency and cost effectiveness of conservation and PES programs, while simultaneously decreasing uncertainty for the purchasers of the environmental goods. The experimental and theoretical results support this claim, showing that the PPRA can save the procurer between 21.55% to 58.17% or 12.57% to 21.59% of their costs on average, when comparing to a multiunit reverse discriminative auction or budget-constrained multiunit reverse discriminative auction, respectively, with the exact value dependent upon the target number of contracts. Given that environmental or conservation goods often include positive externalities, lower offers can lead to welfare increases for society. Further, the PPRA also improves social efficiency over the multiunit reverse discriminative auction, reducing the total cost of the environmental service to society. Future research will expand the empirical support for the PPRA to field settings or continue theoretical examination to consider optimal offering behavior in multiple rounds. Settings where environmental benefits are a function of spatial proximity of conserved land also provide a particularly fruitful area of research.

CHAPTER 2

UNCERTAINTY IN PREFERENCES AND BEHAVIORAL ANOMALIES

2.1 Abstract

Recent research has considered the possibility that uncertainty in preferences plays a role in observed behavioral anomalies. This paper builds upon this work by using experimental methods to vary individual uncertainty in a laboratory setting and measure the resulting change in behavior. The first set of experiments examines the effect of uncertainty in preferences on exchange asymmetries, a well-established phenomena where individuals who are randomly endowed with an item are less likely to trade that item for an alternative. Participants were randomly endowed with one of two varieties of chocolate, with the two varieties only identified by a shape stapled to otherwise identical bags. In the control sessions, participants were asked whether they would like to trade their chocolate for the alternate variety with no further information. In the treatment sessions, individuals were allowed to taste each variety of chocolate before making their decision. While large exchange asymmetries were observed in control sessions, no exchange asymmetry was observed in the treatment sessions, suggesting that uncertainty in preferences may play a large role in the behavioral anomaly. The second set of experiments examines the effect of uncertainty in preferences on the WTA/WTP disparity. Some participants were randomly endowed with chocolate while others were not. After valuing a sequence of assets which yielded random returns, the participants were asked to use a BDM to estimate their willingness to accept or willingness to pay for the chocolate. In the treatment sessions, the participants were allowed to taste a small amount of

the chocolate before making a decision. While a WTA/WTP disparity was observed in both treatment and control sessions, the magnitude of the disparity was smaller in the treatment session than in the control session. These results suggest that uncertainty in preferences may play a large role in the magnitude of observed WTA/WTP disparities as well. Given that individuals are often very uncertain about their preferences for environmental amenities, the results are particularly important for environmental economics and contingent valuation.

2.2 Introduction

Exchange asymmetries occur when individuals who are endowed with a good are less likely to trade that good for an alternative. If 30 people are randomly endowed with a bar of chocolate and another 30 people are randomly endowed with a coffee mug, individuals with reversible indifference curves will, on average, trade their item for the alternate 50% of the time, regardless of the preferences of the population. For example, if 90% of individuals prefer the chocolate to the mug, then, on average, 27 of the 30 people endowed with the mug will trade for the chocolate and 3 of the 30 people endowed with the chocolate will trade for the mug for a total of 30 out of 60 possible trades. An exchange asymmetry has occurred when less than 50% of the population trades their item for the alternate. A similar behavioral anomaly, the willingness-to-accept/willingness-to-pay (WTA/WTP) disparity, occurs when individuals indicate a willingness-to-accept to lose a good that is much higher than a willingness-to-pay for that good. Both of the above anomalies clash with standard and commonly used assumptions in economic theory, many of which imply that ownership of a good should not impact an individual's preference for that good.

The implications of these anomalies are significant and broad. For example, if WTA is truly higher than WTP for most individuals and goods, then measuring WTA instead of WTP in contingent valuation studies will have a great impact on the estimated values for the environment. Kim, Kling, and Zhao consider four possible cases in their review of the WTA/WTP disparity and environmental policy:[24]

1. For an environmental improvement, if the property rights lie with the environmental improvement, then willingness to accept for not receiving the improvement should be measured.
2. For an environmental improvement, if the property rights lie with the degraded environment, then willingness to pay for the improvement should be measured.
3. For an environmental degradation, if the property rights lie with the environmental improvement, then willingness to accept for obtaining the degradation should be measured.
4. For an environmental degradation, if the property rights lie with the degraded environment, then willingness to pay to avoid the degradation should be measured.

The disparity between WTA and WTP is often economically substantial. Horowitz and McConnell, in their review of WTA/WTP studies, find a mean WTA/WTP ratio of 7; that is, their review of the literature suggests that an individual's WTA for a good is, on average, seven times their WTP for that same good. [19] The authors suggest that such a high WTA/WTP ratio could have profound effects on land preservation in the United States and abroad. Borges and Knetsch suggest that trade and profit forecasts would be severely flawed if a WTA-WTP disparity exists but is not accounted for. [4] Additionally, if the ownership of a good is relevant for it's final value, then the assignment of property rights is critically important, and would likely negate a central requirement of the Coase Theorem.

The literature investigating the endowment effect has largely focused on theories of loss aversion [23], substitutability [16], and experimental validity [39, 40]. A smaller portion of the literature has considered the possibility that imprecise preferences might explain at least part of the observed behavioral anomalies, including the WTP/WTA disparity, exchange asymmetries, and preference reversals. [9, 32] Unfortunately, the experimental evidence on this topic is limited.

This paper contributes to the experimental and behavioral economics literature by running laboratory experiments to directly measure the effect of uncertainty in preferences on the existence and magnitude of behavioral anomalies. Identifying changes in uncertainty can be challenging. This paper uses chocolate and a "taste" treatment to change the information individuals have about their own preferences. While some previous papers have included a "taste" component in their experimental design, none have done so in a way which allows for causal comparisons across information levels. [9, 18] In the first set of experiments, half of the participants are randomly endowed with one variety of chocolate and the other half of participants are endowed with a different variety of chocolate. In control sessions, the participants are given almost no information about the chocolate and asked if they would like to trade their variety of chocolate for the alternate variety. In the treatment sessions, individuals are given the opportunity to taste small amounts of both varieties of chocolate before they make their trade decisions. Individuals with reversible indifference curves (a common assumption in micro-economic theory) should, on average, trade 50% of the time, regardless of the population's preferences between the two varieties of chocolate. In the control sessions, almost no participants traded their chocolate for the alternate variety; that is, we observe a large exchange asymmetry. In the treatment sessions, however, almost 50% of participants traded, matching standard economic theory. These results suggest that, in at least some settings, uncertainty in preferences may explain some, or even all, of the observed exchange asymmetries.

A second set of experiments uses a similar taste treatment to examine the role that uncertainty in preferences may play in the WTA/WTP disparity. In both treatment and control sessions, half of the participants were endowed with an unmarked bag of chocolate. Participants then engaged in a sequence of Becker-Degroot-Marschak (BDM) auctions for lotteries to build familiarity with the mechanism. [3] Once these auctions were completed, the WTA and WTP of the participants for the chocolate was elicited, again using a BDM. In the treatment sessions, participants were allowed to taste a small amount of the chocolate before making their decisions. The results show that, while a statistically significant WTA/WTP disparity was observed in both treatment and control sessions, the magnitude of the disparity was substantially diminished in the treatment sessions.

2.3 Theory and Literature Review

2.3.1 Uncertainty in Preferences

There is a small, but growing, literature discussing the relationship between uncertainty in preferences and the WTA/WTP disparity. The most common form of uncertainty considered in the literature is 'product uncertainty': an uncertainty over or imprecision in one's own valuations of the good itself, usually due to a lack of familiarity [12, 18]. Loomes et al. (2009) refer to this as 'intrinsic uncertainty' which they distinguish from uncertainty regarding the states in which a good will be consumed, or 'extrinsic uncertainty' [32]. This paper considers the effect intrinsic uncertainty may have on behavioral anomalies by experimentally varying the probabilities of "taste" states.

In their work on uncertain preferences, Dubourg, Jones-Lee, and Loomes suggest that, in many settings, people have neither enough time for introspection nor enough information about the relevant product to form precise valuations. [12] Instead, they might only be able to identify a range within which their true value lies. The authors refer to these ranges as "personal confidence intervals". They suggest that such a setting can credibly explain a significant part of the WTA/WTP disparity, as caution or bargaining instincts may lead people to both draw a value from the lower end of the range when asked for their willingness to pay, and choose a value from the upper end of the range when asked to report their willingness to accept. This intuition is similar to individuals implementing a maximin expected utility strategy in the face of uncertain outcomes as suggested by Schmeidler et al. [47]. Under the Dubourg et al. framework, allowing participants to taste the chocolate would effectively collapse the corresponding personal confidence intervals to a single point (their true preference for the chocolate), thereby eliminating any WTA/WTP disparity.

Zhao and Kling, in their research on the cost of commitment, suggest that even for individuals who do not exhibit loss aversion or the endowment effect, a WTA/WTP disparity can be observed in a dynamic setting if there is a cost to committing to a good for which their value is uncertain. [53, 54] In the authors' model, commitment costs occur when: (1) the individual is uncertain about the value of the good, (2) the individual anticipates that they will be able to learn more about the good's value in the future, (3) the individual has some willingness to wait for that additional information, (4) there is a cost associated with reversing the acquisition or loss of the good, and (5) the individual is forced to make their trading decision in the present. In the experiments discussed in this paper, we consider static, one-shot decisions in which there are no transaction costs, as defined above. While there is certainly uncertainty regarding the value of the good, there is no opportunity to trade the good once the experiment has concluded. The following theory and experimental results in this paper suggest that commitment costs are not required for uncertainty in preferences to impact the WTA/WTP disparity.

A final form of uncertainty discussed in the literature is uncertainty regarding the valuation mechanism and market inexperience. For example, if individuals are unsure how a BDM works, they may state values which are inaccurate, which may result in behavioral anomalies. Several authors have conducted work examining the effect of market experience on behavioral anomalies, including the WTA/WTP disparity and preference reversals [9, 39, 30, 31]. The general finding from this body of research is that market experience at least diminishes the WTA/WTP disparity, and in many papers the disparity vanishes altogether. To accomodate this possibility, the experiments conducted for this paper include several practice and paid rounds with a BDM to ensure participants had market experience before making their chocolate valuation decisions.

2.3.2 WTA/WTP Disparity: Loomes et al. Results

In their paper on taste uncertainty and status quo effects, Loomes, Orr, and Sugden establish a theoretical framework for examining the effect of uncertainty in preferences on behavioral anomalies [32]. Their framework builds on the existing state-dependent and reference-dependent utility literature [45, 25, 48]. As far as this author is aware, only one other paper has attempted to experimentally examine the effect of uncertainty in preferences on behavioral anomalies within the Loomes et al. framework [13]. Georgantzís and Nikolaos and Navarro-Martínez use a survey to measure participants' knowledge of goods, along with other attitudinal factors. They find that differences in personality profiles contribute to the WTA/WTP gap. In particular, their results suggest that risk aversion and familiarity with the good may be correlated with elicited WTA, but not WTP. This paper provides a more rigorous causal mechanism by using a "taste" treatment which does not rely on individuals' stated uncertainty. This section will first introduce the theory and results presented by Loomes et al. (2009), and then consider the experiments conducted in this paper within their framework.

Suppose that the set of all states is given by $S = \{s_1, ..., s_m\}$, and that all bundles generate a "consequence" in any state. For example, the bundle x generates the consequence $c(x, s_h)$ when state s_h is realized. Following reference dependent stated expected utility theory (RDSEUT), as introduced by Sugden, we require three functions to specify preference relations [48]. First, we have a probability function, $\Pi(\cdot)$ with $\sum_h \Pi(s_h) = 1$, which gives the probability that any given state will occur. Second, we have a utility function, $u(\cdot)$, which assigns a number to each possible "consequence." Finally, we have a gain/loss evaluation function, $\phi(\cdot)$, which we assume is continuous and weakly concave, with $\phi(0) = 0$. Building on RDSEUT, Loomes et al. say that the bundle x is preferred to the bundle y, conditional on the current reference bundle z, if and only if:

$$\sum_h \Pi(s_h)\phi(u_h[c(x, s_h)] - u_h[c(z, s_h)]) \geq \sum_h \Pi(s_h)\phi(u_h[c(y, s_h)] - u_h[c(z, s_h)]) \quad (2.1)$$

From this point, $u_h[c(x, s_h)]$ will be simplified to $u_h[x]$ for notational convenience. If $\phi(\cdot)$ is a linear function, then (2.1) yields the results from expected utility theory; willingness to accept equals willingness to pay. If $\phi(\cdot)$ is concave, however, individuals with the above preferences will exhibit loss aversion; this reflects the intuition that individuals experience losses more severely than gains of the same magnitude. Let U_h and V_h describe the marginal utilities of goods 1 and 2 evaluated at the reference bundle z, respectively. That is, $U_h = \frac{\partial u_h(x_1,x_2)}{\partial x_1}$ and $U_h = \frac{\partial u_h(x_1,x_2)}{\partial x_2}$. We can normalize the units of the two goods so that:

$$\sum_h \Pi(s_h)U_h = \sum_h \Pi(s_h)V_h = 1 \quad (2.2)$$

Next, the authors indexed the states so that $U_1/V_1 \geq U_2/V_2 \geq ... \geq U_m/V_m$. That is, the states are indexed so that the smallest numbered states have the largest relative preference for good 1 compared to good 2. Finally, $\phi(\cdot)$ is normalized so that $\phi'(t)$ converges to 1 as t converges to 0 from above and $\phi'(t)$ converges to β as t converges to 0 from below. The larger β, the larger the disparity between the value attributed to equally sized gains and losses. Denote the marginal willingness to accept for good 1 in terms of good 2 by r_{21}^{WTA}. r_{21}^{WTA} provides the amount of good 2 that an individual must be given to compensate them for the loss of one unit of good 1. Note that:

$$r_{21}^{WTA} = \frac{1}{r_{12}^{WTP}} \tag{2.3}$$

To see that (2.3) holds, consider a scenario where an individual has 10 units of good 1 and 5 units of good 2. If $r_{21}^{WTA} = 1.5$, then the individual is indifferent between the bundle $(x_1 = 10, x_2 = 5)$ and $(x_1 = 9, x_2 = 6.5)$. Given that the individual is indifferent between those two bundles, the individual must also be willing to pay one unit of good 1 to gain 1.5 units of good 2; that is, $r_{12}^{WTP} = \frac{1}{1.5} = \frac{1}{r_{21}^{WTA}}$.

If r_{21}^{WTA} is known, then all states can be split into loss states $(L = \{s_1, ..., s_K\})$ and gain states $(G = \{s_{K+1}, ..., s_m\})$, where K is such that $U_h/V_h \geq r_{21}^{WTA}$ for $s_1, ..., s_K$, and $U_h/V_h < r_{21}^{WTA}$ for $s_{K+1}, ..., s_m$. Suppose that an individual with these preferences is given r_{21}^{WTA} units of good 2 in exchange for a unit of good 1. Then, given that the individual is indifferent to the exchange, we have:

$$\sum_{h \in L} \Pi(s_h)\beta(r_{21}^{WTA} V_h - U_h) + \sum_{h \in G} \Pi(s_h)(r_{21}^{WTA} V_h - U_h) = 0 \tag{2.4}$$

Rearranging this equation yields[1]:

$$r_{21}^{WTA} = \frac{[\beta \sum_{h \in L} \Pi(s_h) U_h + \sum_{h \in G} \Pi(s_h) U_h]}{[\beta \sum_{h \in L} \Pi(s_h) V_h + \sum_{h \in G} \Pi(s_h) V_h]} \tag{2.5}$$

[1] r_{12}^{WTA} can be derived using a similar method.

Given (2.2), when $\beta = 1$, $r_{21}^{WTA} = r_{12}^{WTA} = 1$. Additionally, given (2.3), when $\beta = 1$, there is no WTA/WTP disparity. If, however, $\beta > 1$, the additional weight added to the "loss" states results in a WTA/WTP disparity which increases as β increases. That is, under RDSEUT and in the presence of both loss aversion and intrinsic uncertainty, we expect a WTA/WTP disparity. Even more, the magnitude of that disparity increases as β increases.

2.3.3 WTA/WTP Disparity: Loomes et al. Application

As detailed in Section 2.4, participants in the WTA/WTP disparity control sessions were asked to value an unmarked bag of chocolate using a BDM, while participants in the treatment sessions were allowed to taste a small amount of the chocolate before stating their value. To interpret these experiments in reference to Loomes et al. (2009), suppose that ex ante, participants believe that there are only two states: s_G, where the chocolate tastes good, and s_B, where the chocolate tastes bad.[2] In control sessions, each individual participant has some subjective prediction about the probability of each state, given by $\Pi(s_G)$ and $\Pi(s_B)$. In treatment sessions, the small taste of chocolate eliminates all uncertainty about the "taste" state outcome; that is, either $\Pi(s_G)$ or $\Pi(s_B)$ becomes 1. In this section, we show that, using the same assumptions as Loomes et al. (2009), as the probability of one state converges to 1, the WTA/WTP disparity converges to 0, even in the presence of loss aversion. [32]

In this paper's WTA/WTP disparity experiments, bundles consist of two goods: chocolate and money. For individuals endowed with chocolate (that is, individuals

[2]The theoretical predictions shown hold when the number of possible states accounts for a larger variety of discrete taste outcomes.

submitting a WTA value) the reference bundle can therefore be represented as $z = (chocolate, w(\$))$, where w represents the initial wealth of the participant at the time of exchange. Given the incentive compatibility of the BDM, the elicited WTA is such that

$$x = (chocolate, w(\$)) \quad \sim \quad y = (0, w + WTA(\$)) \tag{2.6}$$

That is, participants are indifferent between keeping the chocolate and their original wealth, or giving up the chocolate in exchange for a payment in the amount of WTA.

Given the initial bundle, we can denote the marginal utilities for chocolate under the good and bad taste states as U_G and U_B. Since the value of money is not contingent on the taste state and changes in income within the experiment and across treatments are small, it is reasonable to assume that there is only one relevant marginal utility of money relative to the reference state, which we will denote by V. In this case, (2.5) reduces to

$$r_{c,\$}^{WTA} = \frac{[\beta\Pi(s_B)U_B + \Pi(s_G)U_G]}{[\beta\Pi(s_B)V + \Pi(s_G)V]} \tag{2.7}$$

Under the treatment condition, participants are able to learn which taste state has occurred in practice. That is, either the chocolate tastes bad ($\Pi(s_B) = 1$ and $\Pi(s_G) = 0$) or the chocolate tastes good ($\Pi(s_B) = 0$ and $\Pi(s_G) = 1$.) Given the normalization in (2.2), this implies that $U_B = V$ when $\Pi(s_B) = 1$ and $U_G = V$ when $\Pi(s_G) = 1$. Thus, with the full taste treatment, the model predicts $r_{c,\$}^{WTA} = 1$ under the relevant normalization. The same can be shown for $r_{\$,c}^{WTA}$, which is equivalent to $1/r_{c,\$}^{WTP}$ from (2.8). This implies that the WTA/WTP ratio must equal 1. We can thus conclude that, when individuals are given certainty about "taste" state outcomes, the model predicts no WTA/WTP disparity even in the presence of loss aversion.

The same result can be shown more intuitively using explicit differences in absolute utility. Recalling that participants endowed with chocolate face an initial reference bundle $z = (chocolate, w(\$))$ and using the bundles given in (2.6), a BDM elicits a WTA such that:

$$\begin{aligned} &\Pi(s_G)\phi(u_G[x] - u_G[z]) + \Pi(s_B)\phi(u_B[x] - u_B[z]) \\ =&\Pi(s_G)\phi(u_G[y] - u_G[z]) + \Pi(s_B)\phi(u_B[y] - u_B[z]) \end{aligned} \tag{2.8}$$

The above equation states that WTA will be chosen to equate the sum of probability-weighted utility across states, accounting for the loss aversion resulting from the $\phi(\cdot)$ function. This equation follows directly from RDSEUT. In the experimental context of this paper, the left-hand side of the above equation equals 0 since x and z are the same bundle; that is, if you do not sell your chocolate, you have the same bundle as your initial endowment. Note that, by the definition of the states and bundles, $(u_G[y] - u_G[z]) < 0$ while $(u_B[y] - u_B[z]) > 0$. (I.e., when the good state occurs, if you sell your chocolate when you gave WTA(\$) for your value, you are worse off than you would be at your initial endowment, while in the bad state, if you sell your chocolate when you gave WTA(\$) for your value, you are better off than you would be at your initial endowment.) Additionally, we know that the following holds:

$$|(u_G[y] - u_G[z])| < |(u_B[y] - u_B[z])| \tag{2.9}$$

The above follows from the loss aversion inherent in $\phi(\cdot)$ which amplifies the loss associated with giving up the chocolate in state s_G. Thus, in control sessions, loss aversion may affect WTA and cause a WTA/WTP disparity. Recall that under the treatment condition, however, either $\Pi(s_G) = 0$ or $\Pi(s_B) = 0$. In order for the equality in (2.8) to hold, either $\Pi(s_G) = 1$ and

$$\phi(u_G[y] - u_G[z]) = 0 \tag{2.10}$$

or $\Pi(s_B) = 1$ and

$$\phi(u_B[y] - u_B[z]) = 0 \tag{2.11}$$

Since $\phi(\cdot)$ is assumed to be continuous, increasing and weakly concave with $\phi(0) = 0$, the only way (2.10) or (2.11) can hold is if $u_G[y] - u_G[z] = 0$ when $\Pi(s_G) = 1$ or $u_B[y] - u_B[z] = 0$ when $\Pi(s_B) = 1$.[3] Assuming that the utility function, $u(\cdot)$, satisfies the requirements of rational expected utility theory (as assumed by Loomes et al. (2009) and RDSEUT), the irrelevance of $\phi(\cdot)$ when one of the states is certain to occur implies that WTA will be chosen to equate utility across bundles within states, regardless of the existence of loss aversion.

For individuals not endowed with chocolate and asked for their WTP to purchase chocolate, their initial endowment is $z = (0, w(\$))$. The BDM's incentive compatibility should result in WTP values that satisfy:

[3] Note that the WTA elicited under the treatment and control condition will differ based on this reduction in taste state uncertainty, meaning that lottery y differs in terms of the relevant amount of money under these scenarios.

$$a = (0, w(\$)) \quad \sim \quad b = (chocolate, w - WTP(\$)) \tag{2.12}$$

That is, even in the presence of loss aversion, an individual's elicited WTP should lead to indifference between purchasing the chocolate and losing money and not purchasing chocolate and keeping all their wealth. The WTP version of (2.8) is

$$\begin{aligned} &\Pi(s_G)\phi(u_G[a] - u_G[z]) + \Pi(s_B)\phi(u_B[a] - u_B[z]) \\ =&\Pi(s_G)\phi(u_G[b] - u_G[z]) + \Pi(s_B)\phi(u_B[b] - u_B[z]) \end{aligned} \tag{2.13}$$

Similar to before, the above equation states that WTP will be chosen to equate the sum of probability-weighted utility across states, accounting for the loss aversion resulting from the $\phi(\cdot)$ function. Once again, because a and z represent the same bundle, the left hand side of (2.13) is 0. As before, when there is uncertainty over which taste state can occur, loss aversion can yield a WTP which is not equal to the individual's true value for the chocolate. When there is certainty over which state will occur, however, either $\Pi(s_G) = 1$ and

$$\phi(u_G[a] - u_G[z]) = 0 \tag{2.14}$$

or $\Pi(s_B) = 1$ and

$$\phi(u_B[b] - u_B[z]) = 0 \tag{2.15}$$

This yields a similar conclusion to the one above: the irrelevance of $\phi(\cdot)$ when one state is certain to occur implies that WTP will be chosen to equate utility across bundles within states, regardless of loss aversion. When differences in wealth between WTA and WTP individuals are sufficient to account for any possible income effects, the resulting WTA and WTP values should be equivalent, on average, across the population.

2.3.4 Uncertainty in Preferences and Exchange Asymmetries

The above theory assumed that the source of uncertainty was limited to the quality of the chocolate, but an additional possible source of uncertainty is translating the value for chocolate into its monetary equivalent. That is, the taste treatment allows participants to know whether they like the chocolate or not, but it does not guarantee that individuals will know with precision how much they value that chocolate in dollars. Indeed, the BDM may fail to elicit the "true" value for the chocolate, even under the "taste" certainty treatment. If individuals have poorly defined or "fuzzy" preferences, there may be no "true" value for the chocolate at all.

Fortunately, the exchange asymmetry experiments avoid these problems, as, unlike the experiments measuring WTA and WTP, the exchange asymmetry sessions do not interact money and chocolate. As discussed in Section 2.4, participants are only given the option to keep their current chocolate or trade for an alternate variety. The most prominent explanation for the existence of exchange asymmetries is the "endowment effect," which suggests that individuals place a greater value on objects they own than on objects they do not possess. An alternate hypothesis states that experimental procedures may account for the anomaly. The experimental design used in this paper is specifically modelled to account for this possibility, as discussed in Section 2.4.[39, 40]

An additional explanation states that transaction costs for trading may account for the disparity. [38] For example, suppose that there are two possible bundles, $x =$ (Square Chocolate) and $y =$ (Circle Chocolate). Now, suppose that an individual prefers the square chocolate bundle to the circle chocolate bundle. In a rational expected utility framework with no costs for trading, an individual who prefers the alternate bundle will always trade for the alternate bundle and an individual who prefers their current bundle will always keep their current bundle. If individuals are randomly endowed with their bundle, on average, about half of participants will trade for the alternate variety, regardless of the preferences of the population. However, suppose that there is a cost for trading, $c > 0$. For some participants, it is possible that this transaction cost would outweigh the gains from trading, resulting in less than the predicted number of trades in the absence of transaction costs and an exchange asymmetry. The larger the transaction cost, the greater the probable asymmetry, until the transaction costs are so great that no individual will trade. In the experiments discussed in this paper, the only transaction costs which occur are the cost of the trade itself: if an individual wishes to trade their chocolate for an alternate variety, they must take their chocolate to the front of the room and and hand it to the researcher at the conclusion of the experiment when they collect their earnings. Nonetheless, even minute transaction costs may cause exchange asymmetries when individuals are very uncertain about the value of their good. For example, if an individual is so uncertain about the relative quality of the “square” and “circle” chocolate that they are essentially indifferent between the two, even a minuscule transaction cost, like the one present in the experiments conducted for this paper, could lead to large exchange asymmetries.

Some researchers have also posited "Query Theory" as a framework which can explain the WTA/WTP disparity.[22] In Query Theory, the process by which individuals value goods affects their final valuation. Specifically, if individuals are endowed with a good and asked for their WTA for the good, they first consider their preferences for the good and then consider their preferences for money. Individuals who are asked for their WTP for a good, however, consider the money first and then construct their value for the good. Query Theory posits that the order of these thought processes matter, that more consideration will be given to the first queries. More simply: sellers focus on the good they would give up and buyers focus on the money they would pay. To substantiate their theory, Johnson et al. conducted experiments which found that when query order is reversed for participants in a lab setting, they can eliminate the endowment effect. It is possible that preference uncertainty and Query Theory interact to increase the magnitude of observed behavioral anomalies. For example, if valuation queries are more difficult for goods with greater intrinsic uncertainty, this may lead to an even greater emphasis placed on the initial queries, further expanding the gap between WTA and WTP.

2.4 Experimental Design

To test the impact of uncertainty in preferences on behavioral anomalies, two sets of experiments were conducted. Experimental participants were limited to students or staff at Cornell University. The first set of experiments examined the impact of uncertainty in preferences on exchange asymmetries. To control for concerns regarding experimental methods and validity, the exchange asymmetry sessions roughly followed the experimental design used by Plott and Zeiler in their exchange asymmetry experiments. [40] Participants were randomly assigned seats upon entering the lab. Each participant was gifted with one of two varieties of chocolate, identified only by a square or circle stapled to the bags (See Appendix B.1 for pictures of the chocolate bags.) The "circle" variety bags contained half of a Ghiradelli "Milk Chocolate & Caramel" bar, while the "square" variety bags contained half of a Ghiradelli "Intense Dark: Twilight Delight" bar. The brand and name of the chocolate bars were not given to the participants, although they were told that both varieties of chocolate were manufactured by the same company. The variety of chocolate given to each participant was determined by their random seat assignment: participants with odd numbered seats were given one variety of chocolate while participants with even numbered seats were given the alternate variety. The assignment of the chocolate was randomized to ensure that participants did not take the gift of their variety of chocolate as a signal of its relative value. Finally, when participants were given the chocolate, it was placed directly on the desk in front of them. They were permitted to handle the bag, but not to open it or look inside. The chocolate was placed in front of the participants to ensure that they felt they had ownership over their good.

Once the participants had been given their chocolate, the researcher read from one of two scripts, depending on whether the session was a treatment or a control session (See Appendix B.2 for the full scripts.) Unlike some of the designs implemented by Plott and Zeiler in their exchange asymmetry experiments, participants in both treatment and control sessions were explicitly told that the chocolate "is a gift. You own it. It is yours." A possible criticism of Plott and Zeiler (2007) is that some of their experimental treatments essentially removed the feeling of endowment. Given that the hypothesis of this paper was that a reduction in uncertainty in preferences would eliminate exchange asymmetries often attributed to the endowment effect, it was essential to ensure that participants felt endowed to allow for a proper comparison of the two theories.

In the treatment sessions, the participants were given the option of tasting a small amount of each variety of chocolate before making their decision. In the control sessions, the participants were told that the "circle" variety chocolate was described as "rich" and the "square" variety of chocolate was described as "luxurious." These descriptions were drawn directly from Ghiradelli's advertising of the two products and were given to the participants to provide a difference (albeit a minor one) between the two varieties. The two scripts were otherwise identical. Before making their trade decisions, participants were asked to complete a short five minute survey (See Appendix B.3.) This survey was included to increase a feeling of endowment by extending the time that participants had ownership over their chocolate. The questions on the survey were modelled after a similar survey used in Plott and Zeiler (2007), which includes many of the same questions. [40] The surveys were not connected to the participants and provide no useful data for this project. Once all participants had completed the survey, participants were given a small piece of paper on which to make their trade decision (See Appendix B.4). These trade decisions were made privately to avoid any possible contamination caused by public trades. Once the sessions concluded, each participant was given a $10 show-up fee and participants traded their chocolate at the front of the room, if they had chosen to do so on their trade sheet. Six exchange asymmetry sessions were conducted between early 2017 and early 2018. Of the six conducted exchange asymmetry sessions, half were treatment sessions and the other half were control. The treatment sessions included 59 total participants, compared to 64 participants in the control sessions.

The second set of experiments examined the effect of uncertainty in preferences on the WTA/WTP disparity. Participants were assigned random seats upon entering the lab. Based on their seat number, half of the participants were endowed with an unmarked bag of chocolate. Again, the assignment of chocolate was randomized to ensure that participants did not interpret the assignment as a signal of value and the bag was placed immediately in front of participants to ensure that participants had a feeling of ownership over the chocolate. As in the first set of experiments, participants given the chocolate were told that the bag of chocolate was theirs, that it was a gift, and that they owned it. Again, this wording was used to give the participants a feeling of ownership over their bag of chocolate. Each bag contained half of a Ghiradelli "Milk Chocolate & Caramel" bar, although the participants were not given this information. All participants were also given a \$5 show-up fee. The participants who were not given chocolate were given an additional \$5. Participants endowed with chocolate were unaware of this additional payment and the un-endowed participants did not know that the endowed participants were not given an extra \$5. The extra payment was needed to compensate the un-endowed participants, as the expected return from purchasing assets in the next phase of the experiment was less than the expected return from selling the assets. Once the participants had completed the consent form, they read instructions on their computer (See Appendix B.5 for the complete instructions.) The sessions consisted of three phases: an instruction and practice period, an asset valuation period, and a chocolate period.

In the first period, the participants were taught to use a Becker-Degroot-Marshak mechanism (BMD) to value assets with random returns. [3] The BDM is an incentive compatible mechanism for measuring an individual's value for a good. The BDM was chosen instead of alternate mechanisms used in other studies, many of which are not incentive compatible, because it has been deemed the most theoretically incentive compatible mechanism by much of the literature. [39] To elicit WTP values[4], the mechanism functions as follows:

1. An individual is presented with a good available for purchase.
2. The individual submits a number which represents their willingness to pay for that good.
3. A random number is drawn from an unknown distribution.[5]
4. If that random number exceeds the elicited WTP, the individual does not purchase the good and keeps their money.
5. If the random number is less than the elicited WTP, the individual purchases the good but pays only the random number, not their stated WTP.

Because no individual can impact the price they would pay for the good by changing their value, the optimal strategy is to reveal their true willingness to pay. For example, suppose you are asked your willingness to pay for an asset which yields \$2.50 100% of the time. Your true WTP for this asset is \$2.50. Suppose that you submit a value less than \$2.50. If the drawn random number is between your stated value and \$2.50, you would miss an opportunity to pay less than \$2.50 for an asset worth \$2.50. If you submit a value greater than \$2.50 and the random draw is between your stated value and \$2.50, you will purchase the asset for more than it is worth and lose money. A similar argument can be made for submitting

[4] A BDM can also be used to elicit WTA values with obvious modifications to the mechanism.

[5] The distribution is unknown to prevent participants from anchoring on the bounds or mean of the distribution. The distribution parameters do not affect the incentive compatibility of the mechanism.

willingness to accept values using a BDM. Individuals who were endowed with chocolate were taught to use a BDM to elicit WTA values while individuals who were not endowed with chocolate were taught to use a BDM which elicits WTP values. Participants were directly told that revealing their true value is the optimal strategy when using a BDM, and they were provided extensive examples and explanations to substantiate that claim (See Appendix B.5.) Similar to the example used above, participants were then asked to value a lottery which yields \$2.50 100% of the time. If participants stated a value other than \$2.50, they were told that they could have improved their expected profit by revealing their true value, with an appropriate explanation dependent on their error. This training was included to prevent subject misconceptions about the mechanism, as described by Plott and Zeiler in their WTA/WTP disparity experiments [39]. This quiz was followed by a practice round where the participants submitted values to either buy or sell an asset with random returns. Participants endowed with chocolate were asked for their WTA to give up their asset while those without chocolate were asked their WTP for the asset. No money changed hands in the practice round and the asset did not yield real returns; the practice round simply provided additional preparation for the subsequent rounds.

After the practice round had completed, the participants valued five assets across five rounds. The parameter values for the assets were constant across individuals; that is, each participant submitted values for identical assets, regardless of whether they were submitting values to buy or sell the asset. As noted above, the participants without chocolate who were submitting WTP values were given an additional \$5 to account for the decreased expected return from purchasing rather than selling the assets. After each participant submitted a value for the asset, they were informed whether they bought/sold the asset, how much they paid/were paid, and whether the asset yielded a return. Participants were also given a running tally of their current earnings, including their show-up fee. Both the unpaid practice round and the paid asset rounds were included in the experimental design to ensure that participants were familiar with the BDM before valuing the chocolate in stage 3.

After the participants valued each of the lotteries, they were asked to value a bag of chocolate using a BDM. Participants without chocolate were given an additional $4 to account for possible income effects. In the treatment sessions, participants were given a small piece of the chocolate to taste before making their decisions. The instructions were otherwise identical across the two treatments. After the participants submitted their values for the chocolate, they were told whether they had bought/sold any chocolate, how much they paid/were paid, and their final earnings for the experiment. Finally, to avoid any public contamination, all of the individual results from the experiment were kept anonymous; participants were paid privately at the front of the room, where they also received or gave chocolate to the researcher, if applicable.

Four WTA/WTP disparity sessions were conducted in the first half of 2018. Of the four sessions, two were treatment sessions where participants had the opportunity to taste the chocolate and two were the no-taste control. In total, 43 individuals participated in the control sessions and 34 individuals participated in the treatment sessions.

2.5 Results

2.5.1 Exchange Asymmetry Experiments

Table 2.1 provides the summary statistics for individuals who participated in exchange asymmetry sessions. While very few trades occurred in the "low-information" control sessions, almost exactly 50% of the participants in the "taste" treatment sessions traded their chocolate for the alternate variety. Table 2.2 displays the results from two-sided exact binomial tests, where the null hypothesis is that the true probability of trade equals 0.5 and the alternate hypothesis is that the true probability does not equal 0.5. In the control sessions, we can easily reject the null hypothesis at all commonly used significance levels, confirming the presence of an exchange asymmetry. In the "taste" treatment sessions, however, we cannot reject the null hypothesis at any commonly used significance level. Thus, we observe no exchange asymmetry in sessions with complete taste information. The results in both sets of treatment sessions are consistent with the theoretical predictions laid out in Section 2.3.

Table 2.3 provides the results for a two-sided difference in proportions test. This test considers the null hypothesis that the true difference in the probability of trade between the two groups is 0 against the alternative hypothesis that the difference in the probability of trade between the two groups is non-zero. Once again, the results are highly significant: the p-value allows us to reject the null hypothesis for all commonly used significance levels.

Participants in the treatment sessions seemed to have a slight preference for the "circle" variety chocolate, on average, with 55.9% of the participants leaving

Table 2.1: Exchange Asymmetry: Summary Statistics and Results

	Control				Taste			
Session	1	2	3	Total	1	2	3	Total
Sample Size	20	22	22	64	23	17	19	59
Square	10	11	11	32	11	9	9	29
Circle	10	11	11	32	12	8	10	30
Square Traded For Circle	0	1	1	2	6	5	5	16
Circle Traded For Square	1	1	1	3	6	3	4	13

Note: The above table contains the summary statistics for the exchange asymmetry sessions. In the "taste" treatment sessions, participants were allowed to sample both varieties of chocolate before making their trading decision. In the control sessions, participants were only told that the "circle" variety of chocolate was described as "rich," while the "square" variety chocolate was described as luxurious. The "Square" row indicates how many participants were randomly endowed with the "square" chocolate and the "Circle" row indicates how many participants were randomly endowed with the "circle" chocolate.

Table 2.2: Exchange Asymmetry: Binomial Test

	Control	Taste
Sample Size	64	59
Total Trades	5	29
Proportion Traded	0.078	0.492
Binomial Test True Prob Trade ≠ 0.5	p = $9*10^{-9}$	p = 1
95% CI	(0.026, 0.173)	(0.359, 0.625)

Note: The above table provides the results of two-sided exact binomial tests. The null hypothesis is that the true probability of trade = 0.5. The p-value from the binomial test for the control group suggests that we can reject the null hypothesis at all commonly used statistical significance levels. The p-value from the binomial test for the "taste" treatment group, however, cannot reject the null hypothesis at any commonly used statistical significance level.

Table 2.3: Exchange Asymmetry: Difference in Proportions

	Control	Taste
Sample Size	64	59
Total Trades	5	29
Proportion Traded	0.078	0.492
Diff in Prop	p = $8.663*10^{-7}$	

Note: The above table provides the results of a two-sided difference in proportions test between the "taste" treatment and the control. The resulting Pearson's chi-squared test statistic yields a p-value = $8.663*10^{-7}$, suggesting a highly statistically significant difference in proportions.

the lab with the "circle" chocolate. However, 1) the preference is not statistically significant[6] and 2) the preferences of the population are irrelevant for measuring exchange asymmetries, so long as half of the population is randomly endowed with each variety.

2.5.2 WTA/WTP Disparity Experiments

Table 2.4 provides elicited values submitted by participants for the asset/lottery valuation portion of the experiments. These rounds were not designed to yield meaningful data for causal analysis, but instead provided the participants an opportunity to gain familiarity with the BDM. This data, however, may provide some insight about the comparability of the participants in the treatment sessions and the participants in the control sessions. Differences in mean WTA and WTP between treatments for a given asset were not statistically significant for any asset. The WTA/WTP ratios were higher for most assets in the treatment sessions than the control, but, if the participants in the treatment session did indeed have larger

[6] A two-sided exact binomial test, with a null hypothesis that the true probability of selecting the "circle" variety chocolate = 0.5, yields a p-value = 0.435.

WTA/WTP gaps for all goods, this would lead to attenuation bias in this setting, as results would be biased towards the null hypothesis that uncertainty has no impact on the WTA/WTP disparity.

Table 2.5 provides the individual chocolate valuations by session, treatment, and endowment, and Figure 2.1 displays the responses in a box plot by treatment and endowment. From the table, we can see that there is clearly substantial variation between sessions, but a WTA/WTP disparity is still visible in each session. This is not surprising given the variance in participant valuations seen in Table 2.5. The box plot shows that the taste treatment reduces the variation in elicited valuations and narrows the gap between WTA and WTP. Table 2.6 provides more specifics. The "taste" treatment does indeed decrease the WTA/WTP disparity. The elicited WTA of participants in the "taste" sessions was less than the elicited WTA of participants in the control session, and, using a one-sided t-test, the difference was statistically significant at the 10% level. There was no statistically significant difference in the elicited WTP between treatments, however. A one-sided test is appropriate, in this case, as both the theory from Section 2.3 and the literature suggests that decreases in uncertainty should close the WTA/WTP disparity, not increase it.

Table 2.4: WTA/WTP Disparity: Lotteries Summary Statistics

(Payout, Probability)	n	Practice ($3, 0.6)	Asset 1 ($1.5, 0.9)	Asset 2 ($2, 0.4)	Asset 3 ($1.5, 0.5)	Asset 4 ($1.25, 0.7)	Asset 5 ($2, 0.7)
Taste, WTP	18	1.81	1.19	0.82	0.65	0.87	1.24
Control, WTP	22	2.01	1.28	0.94	0.75	1.31	1.34
Difference		-0.21	-0.09	-0.12	-0.10	-0.44	-0.11
Taste, WTA	16	2.33	1.36	1.33	1.25	1.03	1.72
Control, WTA	21	2.51	1.50	1.32	1.26	1.40	1.69
Difference		-0.19	-0.14	0.01	-0.01	-0.37	0.04
Taste, WTA/WTP Ratio		1.29	1.14	1.63	1.92	1.18	1.39
Control, WTA/WTP Ratio		1.25	1.17	1.42	1.69	1.07	1.25

Note: The above table provides summary statistics and differences in means for participant responses to asset valuation. Each asset (including the asset in the unpaid practice round) can be described using (Payout, Probability), where an asset ($x, p) will yield $x with probability p, and $0 with probability (1-p). The Taste, WTP and Control, WTP rows provide the average WTP responses to the assets within the "taste" and control treatments, respectively, while the Taste, WTA and Control, WTA rows provide the average WTA responses for the assets within their respective treatments. The difference rows provide the difference between either the stated WTP values or the stated WTA values. Using a two-sided t-test, none of these differences are statistically significant at the 10% significance level.

Table 2.5: WTA/WTP Disparity: Individual Responses by Session

Session	Treatment	WTA/WTP	Individual Responses	Avg	SD
1	Control	WTA, n=12	3.00, 3.00, 3.00, 3.00, 10.00, 2.00, 2.25, 1.00, 5.00, 1.00, 0.15, 2.00	2.95	2.55
		WTP, n=12	0.50, 0.00, 0.00, 0.00, 0.61, 1.00, 1.50, 2.54, 0.50, 5.00, 1.50, 0.75	1.16	1.42
4	Control	WTA, n=9	9.00, 2.50, 0.51, 2.00, 5.00, 1.50, 3.00, 10.00, 5.00	4.28	3.32
		WTP, n=10	0.35, 0.00, 0.04, 0.55, 1.50, 2.00, 0.00, 0.51, 5.00, 0.01	1.00	1.56
2	Treatment	WTA, n=6	2.0, 1.5, 3.0, 5.0, 4.0, 3.5	3.17	1.29
		WTP, n=7	2.50, 1.25, 0.50, 0.75, 0.40, 0.00, 1.00	0.91	0.81
3	Treatment	WTA, n=10	0.20, 1.99, 3.50, 1.00, 0.75, 2.00, 1.50, 5.00, 1.50, 1.99	1.94	1.40
		WTP, n=11	1.00, 0.35, 0.00, 6.50, 0.65, 0.00, 0.50, 1.00, 2.00, 1.00, 0.75	1.25	1.83

Note: The above table provides the individual responses to the chocolate valuation BDM by session, treatment, and endowment. In control sessions, individuals endowed with an unmarked bag of chocolate were asked to state their WTA for the chocolate using a BDM, while individuals who were not endowed with the chocolate were ask to stat their WTP using the same mechanism. Individuals in the Treatment session were given the same task, but were allowed to taste a small amount of the chocolate before making their decision. The Avg column provides the mean of the individual responses within sessions by endowment and the SD column provides the corresponding standard deviation.

Table 2.6: WTA/WTP Disparity: Difference in Means

	Taste	Control	Difference
WTA	2.40	3.52	-1.12*
	(1.45)	(2.9)	(0.73)
WTP	1.12	1.08	0.03
	(1.49)	(1.45)	(0.47)
WTA/WTP Ratio	2.14	3.26	N/A

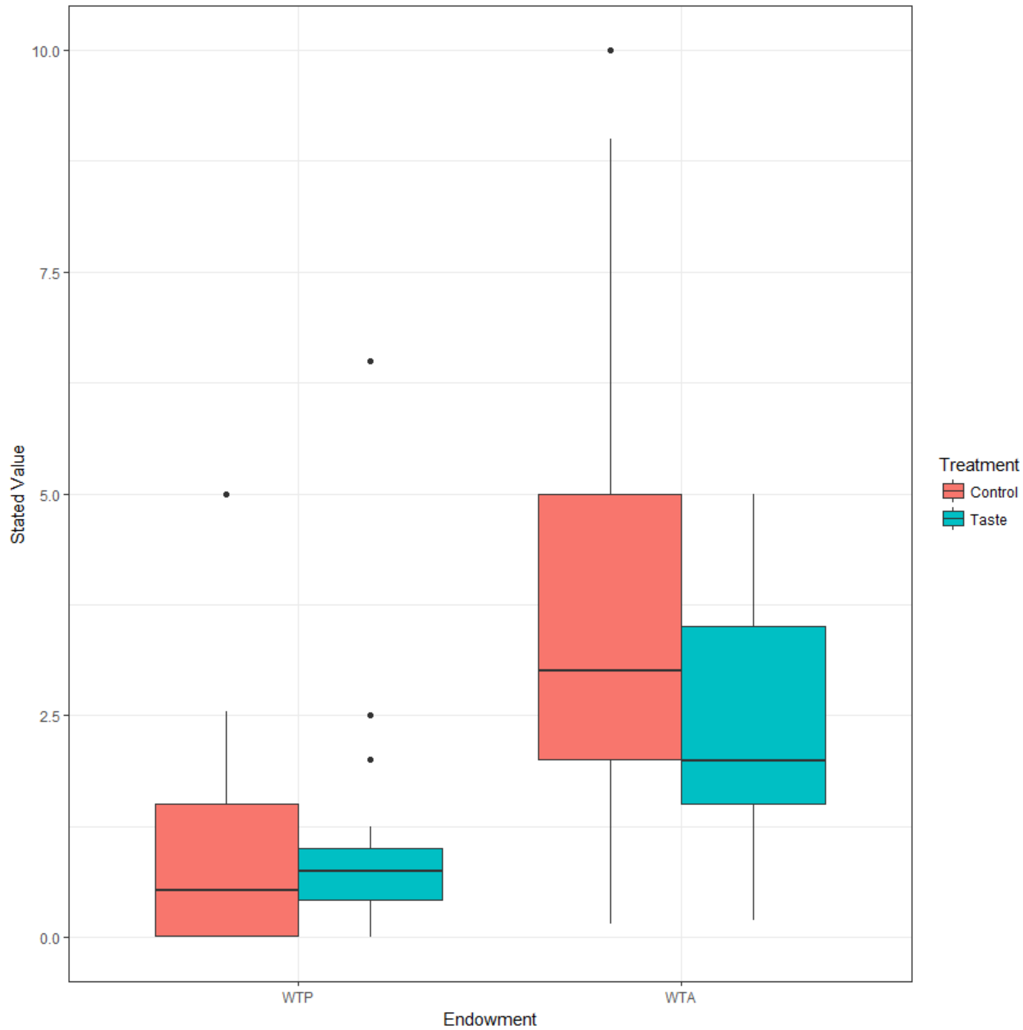
*** p<0.01, ** p<0.05, * p<0.1

Note: The above table provides mean elicited WTA and WTP for the "taste" and control treatments, as well as the difference in mean WTA and WTP between those treatments. The first one-sided t-test was conducted with a total sample of 37, 21 observations in the control group and 16 observations in the treatment group. The second one-sided t-test was conducted with a total sample of 40, 22 observations in the control group and 18 observations in the treatment group.

To check for the possible interference of income effects, we can compare total earnings just before the participants made their chocolate valuations by endowment and across treatments. On average, participants endowed with chocolate had \$10.66 before they submitted their WTA while participants who were not endowed with chocolate had \$14.11 before they submitted their WTP for the chocolate. This difference is nearly identical between treatments, as well, with endowed individuals having \$3.39 more, on average, in the control sessions and \$3.52 more, on average, in the "taste" sessions. Given that the median valuation for the chocolate across all participants was \$1.5, the additional earnings should have prevented any income effect from increasing the WTA/WTP disparity.

We can also check for a "House Money" effect, which hypothesizes that differences in earnings during the asset valuation phase of the experiment may impact the participants' stated values for chocolate. This paper uses the same test as Plott and Zeiler (2005), regressing stated values on earnings immediately before participants valued the chocolate. The estimated coefficients are given in Equations

Figure 2.1: Box Plot of Chocolate Valuations by Treatment



(2.16) and (2.17) below.

$$WTA_i = 4.317 - 0.120 * I_i \qquad (2.16)$$
$$(t = 1.594) \quad (t = -0.478)$$

$$WTP_i = -0.826 + 0.137 * I_i \qquad (2.17)$$
$$(t = -0.330) \quad (t = 0.177)$$

where I_i represents individual $i's$ total earnings prior to submitting their value for the chocolate using a BDM. The results of both regressions suggest that there is no house money effect. That is, the results suggest that differences in earnings during the asset valuation phase of the experiments had no impact on the values submitted for chocolate. Indeed, both of the estimated coefficients on earnings are close the zero and statistically insignificant at all commonly used significance levels.

2.6 Discussion

The results from both sets of experiments suggest that uncertainty in preferences may play a large role in the occurrence and magnitude of behavioral anomalies. In the exchange asymmetry experiments, if the participants were given complete information about their tastes, almost exactly 50% of trades occurred, while a large exchange asymmetry was observed in the low information treatment. The design of the experiment also controlled for other possible forms of uncertainty. First, because the chocolate had been removed from its original packaging, it was not possible for participants to learn the price of the chocolate after the experiment and exchange it for money or an alternate variety. Second, most participants ate the chocolate as soon as the experiment concluded, so there was minimal uncertainty regarding the state of the world in which the chocolate would be consumed. Finally, participants were told that all of the bags of chocolate contained the same weight of chocolate, and thus there was no uncertainty regarding the quantity of chocolate that they would be able to consume.

Transaction costs provide an alternate explanation for the large exchange asymmetries observed in the control sessions. When participants are nearly indifferent between two goods, transaction costs may also contribute to a relative absence of trades. [38] Given the minimal information given to participants in the control sessions, this is a distinct possibility. A potentially fruitful area of future research will examine the interaction between transaction costs and uncertainty. Indeed, it seems plausible that the more uncertain individuals are about their preferences, the larger transaction costs will loom in decision-making.

While the results from the WTA/WTP experiments also suggest that uncertainty in preferences may play a role in the WTA/WTP disparity, the results are less conclusive. First, while the observed disparity in the "taste" sessions does see an economically significant decrease compared to the disparity observed in the control sessions, the difference is less statically significant than the results from the exchange asymmetry experiments. This is likely a function both of the relative sample sizes between the two sets of experiments and the large variation in stated values across participants in the WTA/WTP sessions. Second, while exchange asymmetries disappear altogether in the first set of experiments, the WTA/WTP disparity remains even for participants who received the "taste" treatment. An obvious potential explanation for the persistence of the WTA/WTP disparity is the continued influence of loss aversion or the endowment effect, even after controlling for the influence of intrinsic uncertainty. That is, it is possible that uncertainty in preferences is only one part of a larger set of factors which result in the behavioral anomaly. Another possible explanation, however, is that the taste treatment in the WTA/WTP experiments did not fully alleviate all uncertainty. The "taste" treatment certainly reduced or eliminated the uncertainty regarding the utility that the chocolate would provide, but the participants still had to translate that utility into dollars using a BDM. If participants still had a "personal confidence interval" for their monetary valuation for the chocolate after the taste treatment, it is possible the participants selected their WTA values from the upper end of that interval and their WTP estimates from the lower end of the interval, as predicted by Dubourg, Jones-Lee, and Loomes. [12] That is, it is possible that the "taste" treatment reduced the size of that interval, but did not close the interval entirely, resulting in a smaller but still statistically significant WTA/WTP disparity. Given that the exchange asymmetry experiments 1) eliminated all uncertainty because no money was involved in the trade, and 2) no behavioral anomaly was detected once participants had complete certainty, this author finds the later explanation for the persistence of the WTA/WTP disparity more compelling. Additional work could examine uncertainty and exchange asymmetries when one of the two possible goods is a randomly drawn quantity of money.

Given the recent work on experimental procedures and their influence on laboratory results, the experiments in this paper were designed to control, as much as possible, for confounding factors. Unlike previous work which shows that the WTA/WTP disparity can be eliminated under certain experimental designs, this paper finds a WTA/WTP disparity in all treatments and sessions. It is possible that the persistence of the WTA/WTP disparity in both the "taste" and control treatments, compared to the results of Plott and Zeiler (2005), is due to the emphasis placed on ownership and endowment given in the instructions. However, the primary goal of this project was not to eliminate the WTA/WTP disparity, but to show that uncertainty in preferences can explain a large portion of the disparity in contexts where individuals are endowed with a good for which they have uncertain preferences. Removing or diminishing the sense of endowment to reduce the disparity would, therefore, have been counterproductive. The design of the experiments was otherwise chosen to mimic the protocol with which Plott and

Zeiler eliminated the disparity.

2.7 Conclusion

This paper explored the possibility that a significant portion of an important set of behavioral anomalies could be explained by uncertainty in preferences using laboratory experiments. Specifically, this paper used a “taste” treatment to exogenously vary participants uncertainty and measure the impact of that variation on the WTA/WTP disparity and exchange asymmetries. Participants in the “taste” treatment sessions were allowed to taste small quantities of chocolate before either valuing it or making trade decisions. In the first set of experiments, large exchange asymmetries were observed in control sessions where participants had very little information about the chocolate they possessed and the alternate variety of chocolate for which they could trade. This result conforms to much of the existing literature on the behavioral anomaly. However, in the treatment sessions where participants were allowed to taste both varieties of chocolate before trading, no exchange asymmetries were observed.

The second set of experiments examined the effect of uncertainty in preferences on the WTA/WTP disparity. Participants in both control and “taste’ sessions used a Becker-DeGroot-Marschak mechanism to value a sequence of assets before stating either their WTA or WTP for a bag of chocolate, depending on whether they were randomly endowed with chocolate or not. Participants in the “taste” session were allowed to taste a small amount of chocolate before stating their values. While statistically significant disparities were observed in all sessions across both treatments, the magnitude of the disparity was economically and statistically lower in the "taste" sessions than in the control.

Collectively, both sets of experiments suggest that uncertainty in preferences plays a significant role in the occurrence and magnitude of observed behavioral anomalies. Given the relative paucity of work dedicated to studying uncertain preferences, this result is significant for behavioral and experimental economics, and suggests that more work in this area is justified. The results also hold special significance for environmental economics, where researchers have studied the disparity between willingness to accept and willingness to pay for environmental goods for which consumers often have highly uncertain preferences.

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APPENDIX A

PROVISION POINT REVERSE AUCTION - APPENDIX

A.1 Multiunit Reverse Discriminative Auction Symmetric Optimal Offer Function

I confirm the symmetric Bayseian Nash equilibrium found by Hailu, Schilizzi and Thoyer (2005). In a multiunit reverse auction (also known as a target-constrained auction), a participant in the auction is interested in the probability that their offer will be one of the p lowest offers out of the n offers submitted by the n participants. This probability is represented by $g(O_j^{-1}(o_i))$ in (1.5). The expected profit for an individual in this auction is then represented by

$$E[\Pi] = (o_i - v_i) \times g(O_j^{-1}(o_i)) \tag{A.1}$$

which is a more specific representation of (1.4). The first order conditions to maximize (A.1) are

$$g(O_j^{-1}(o_i)) + (o_i - v_i)\frac{\partial g(O_j^{-1}(o_i)}{\partial o_i}\frac{\partial O_j^{-1}(o_i)}{\partial o_i} = 0 \tag{A.2}$$

Recalling that

$$\frac{\partial f^{-1}(x)}{\partial x} = \frac{1}{f'(f^{-1}(x)} \tag{A.3}$$

Equation (A.2) simplifies to

$$g(O_j^{-1}(o_i)) + (o_i - v_i)\frac{\frac{\partial g(O_j^{-1}(o_i)}{\partial o_i}}{\frac{\partial O_j(O_j^{-1}(o_i))}{\partial o_i}} = 0 \tag{A.4}$$

In equilibrium, $o_i = O_j(v_i) = O^*_{i,TC}(v_i)$. Equation (A.4) becomes

$$v_i\frac{\partial g(v_i)}{\partial o_i} = g(v_i)\frac{\partial O^*_{i,TC}(v_i)}{\partial o_i} + O^*_{i,TC}(v_i)\frac{\partial g(v_i)}{\partial o_i} \tag{A.5}$$

Integrating both sides of (A.5) with respect to o_i yields

$$-\int_{v_i}^{1} u\frac{\partial g(u)}{\partial o_i}du = O^*_{i,TC}(v_i)g(v_i) \tag{A.6}$$

Dividing both sides by $g(v_i)$ and noting that $g(1) = 0$, we have

$$O^*_{i,TC}(v_i) = \frac{-\int_{v_i}^{1} u\frac{\partial g(u)}{\partial o_i}du}{-\int_{v_i}^{1} \frac{\partial g(u)}{\partial o_i}du} \tag{A.7}$$

Given that, according to (1.5),

$$\frac{\partial g(u)}{\partial o_i} = \frac{(n-1)!}{(p-1)!(n-p-1)!}u^{p-1}(1-u)^{n-p-1} \tag{A.8}$$

the symmetric Bayesian Nash equilibrium for the multiunit reverse discriminative auction is given by

$$O^*_{i,TC}(v_i) = \frac{\int_{v_i}^{1} u^p(1-u)^{n-p-1}du}{\int_{v_i}^{1} u^{p-1}(1-u)^{n-p-1}du} \tag{A.9}$$

A.2 Instructions: Target-Constrained Auction

INSTRUCTIONS

This experiment is a study of individual decision-making in a group setting. If you follow these instructions carefully and make informed decisions, you will earn money. The money you earn will be paid to you, in cash, after the experiment has concluded. We ask that you do not use any electronic devices during this experiment, including cell phones, tablets, etc. We further ask that you do not communicate with your peers in any capacity. If you have any questions, please raise your hand and the researchers will come to assist you.

In this experiment, you are a member of a group consisting of eight individuals. You and the other seven individuals each own one unit of a good that can be rented out each round. Each unit of the good is indistinguishable from any of the other units owned by your fellow participants. Additionally, each participant in your group will be given an individual valuation for their own unit of the good, which we will call their **opportunity cost (more details will follow)**. Individuals who do not rent out their unit will receive this opportunity cost as payment at the end of each round. A single buyer is interested in renting five units of the good each round. (The buyer is not interested in renting more than five units) The buyer will pay individuals for their units using an **auction.** The auction will be conducted as follows:

- Each round, you will submit an **offer** representing the amount of money for which you would be willing to rent out your unit during that round. (Your offers will be capped at $7 each round. If you try to submit an offer higher than $7, you will be asked to enter a different offer.)
- Your peers will also submit their own offers for their units.
- The buyer will then rank these offers in ascending order and provide contracts to the lowest offer, then the second lowest offer, and so on until the fifth lowest offer.
- If you <u>do</u> receive a contract from the buyer, the buyer will take your unit (for that round) and **you will receive your offer as payment (for that round)**.
- If you <u>do not</u> receive a contract from the buyer, **you will keep your unit and receive your opportunity cost as payment for that round.**

An individual's opportunity cost (in experimental dollars) will be drawn from a **uniform distribution** from **0 to 2**, in increments of 0.01. In other words, you will randomly receive a number between 0 and 2, where each number is equally likely to be drawn. For example, the odds that you receive opportunity cost = 1.15 are the same as the odds that you receive opportunity cost = 0.82 are the same as the odds that you receive opportunity cost = 0.23, etc. As such, each of the eight individuals in your group will be randomly assigned an opportunity cost and will formulate offers given this information. **All individuals in your group know only their own opportunity costs and that the other individuals in their group have opportunity costs drawn from the same distribution. You will not know the opportunity costs of any of your peers.**

After eight rounds, you will be randomly assigned to a new group of eight individuals. (The random assignments were made before this session by drawing numbers from a hat. The assignment will not be based on the offers made in previous rounds.) In addition, you will receive a new opportunity cost, drawn from the same distribution as before. Each of the other 23 participants in this room will also be randomly assigned to a new group of eight individuals, and will also draw new opportunity costs. If there are any questions about this process, please raise your hand and ask one of the researchers.

The experiment will be complete after 16 rounds. All experimental dollars will be converted to real dollars using a one-to-one ratio. Before the experiment begins, the researcher will briefly discuss the experiment with you using a PowerPoint presentation. There will also be five practice rounds where all 24 participants will participate in rounds of the auction. After these rounds, new opportunity costs and groups will be assigned, and the experiment will begin.

Summary

- At the beginning of the experiment, you will receive a randomly drawn opportunity cost between 0 and 2, with each value in that range being equally likely.
- Based on that opportunity cost, each round you will submit an offer to the buyer for your unit.
- For each round, if out of your group of eight, your offer is one of the five lowest offers, you will receive your offer as payment.
- For additional clarification: in order to receive your offer as payment instead of your opportunity cost, your offer must be accepted by the buyer. For your offer to be accepted, your offer must be one of the five lowest. If your offer is not one of the five lowest offers, you will receive your opportunity cost as payment.
- After each round, you will once again have possession of your unit, and will be able to participate in the auction during the next round.
- After eight rounds, you and the other 23 participants in the experiment will be randomly assigned to new groups of eight with new, randomly assigned opportunity costs. You will maintain these new groups and opportunity costs for the remaining 8 rounds.

A.3 Power Point: Target-Constrained Auction

Overview of Experiment

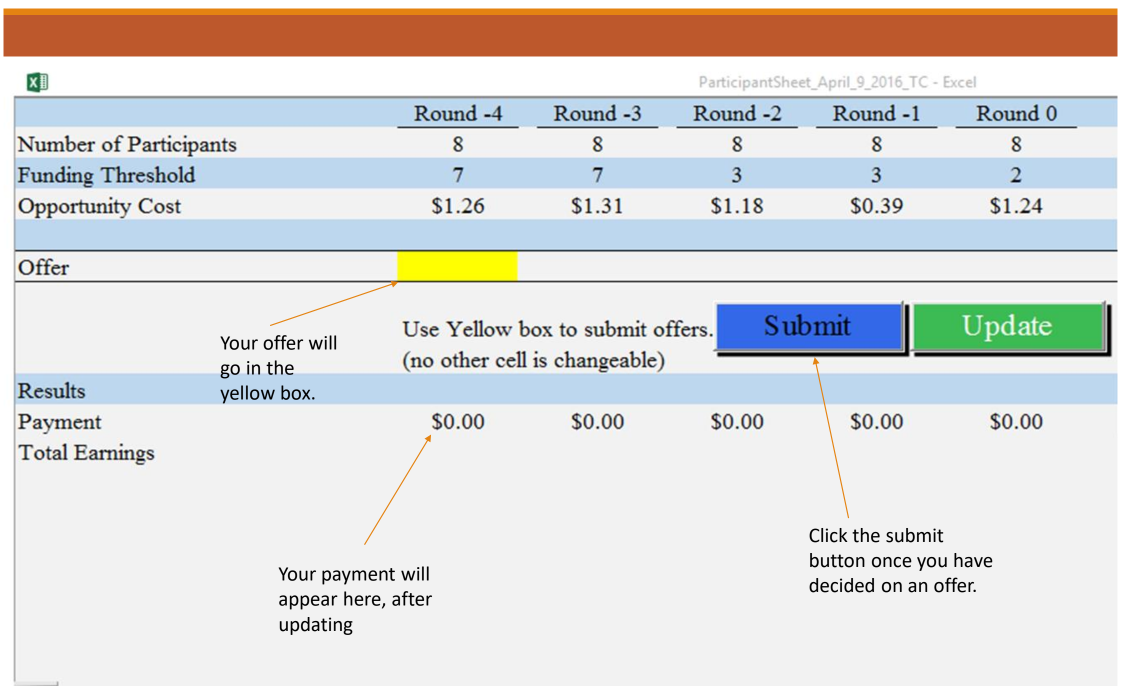
- Throughout this experiment you own one unit of an asset that you can either use yourself or rent out each round. If you keep the unit in a round you can use it yourself for a value which we call your opportunity cost. So, if you don't rent the unit you will be paid your opportunity cost by the experimenter for that round. If you do rent your unit you can not use it but will instead be paid a rent determined in an auction. In order for your unit to be rented, your offer must be one of the three lowest offers submitted by your group.
- Regardless of whether your unit was rented or not, at the beginning of every round, you will once again have possession of your unit, and will submit another offer for the opportunity to rent it.

Overview of Instructions

- You have been randomly assigned to a group of 8 individuals.
- At the beginning of the experiment, you will receive a randomly drawn opportunity cost between 0 and 2, with each value in that range being equally likely.
- You will receive a new randomly assigned opportunity cost after 8 rounds.
- The groups will also be randomly reassigned after 8 rounds.
- Based on your opportunity cost, each round you will submit an offer to the buyer for your unit.
- In a given round, if you receive a contract, you will rent out your unit and receive your offer as payment for that round. (You will earn your offer instead of your opportunity cost as payment.)
- If you do not receive a contract, you will keep your unit and earn your opportunity cost as payment for that round.

Overview of Instructions

- There will be five practice rounds, the results of which will not result in monetary rewards. These rounds are merely for instruction.
- Across these five rounds, the funding threshold will change. The goal of these rounds is simply to detail how the software functions and to ensure that all participants fully understand how the auction works.
- After the five practice rounds, the funding threshold will be fixed at 3, respectively, for all 16 rounds. These rounds will result in monetary rewards at the end of the experiment.



A.4 Instructions: Budget-Constrained Auction

INSTRUCTIONS

This experiment is a study of individual decision-making in a group setting. If you follow these instructions carefully and make informed decisions, you will earn money. The money you earn will be paid to you, in cash, after the experiment has concluded. We ask that you do not use any electronic devices during this experiment, including cell phones, tablets, etc. We further ask that you do not communicate with your peers in any capacity. If you have any questions, please raise your hand and the researchers will come to assist you.

In this experiment, you are a member of a group consisting of eight individuals. You and the other seven individuals each own one unit of a good that can be rented out each round. Each unit of the good is indistinguishable from any of the other units owned by your fellow participants. Additionally, each participant in your group will be given an individual valuation for their own unit of the good, which we will call their **opportunity cost (more details will follow)**. Individuals who do not rent out their unit will receive this opportunity cost as payment at the end of each round. A single buyer is interested in renting units of the good each round. However, the buyer has a limited budget and thus will pay individuals for their units using an **auction.** The auction will be conducted as follows:

- Each round, you will submit an **offer** representing the amount of money for which you would be willing to rent out your unit during that round. (Your offers will be capped at $7 each round. If you try to submit an offer higher than $7, you will be asked to enter a different offer.)
- Your peers will also submit their own offers for their units.
- The buyer will then rank these offers in ascending order and provide contracts to the lowest offer, then the second lowest offer, and so on until the buyer's budget is exhausted.
- If you <u>do</u> receive a contract from the buyer, the buyer will take your unit (for that round) and **you will receive your offer as payment (for that round)**.
- If you <u>do not</u> receive a contract from the buyer, **you will keep your unit and receive your opportunity cost as payment for that round.**

An individual's opportunity cost (in experimental dollars) will be drawn from a **uniform distribution** from **0 to 2**, in increments of 0.01. In other words, you will randomly receive a number between 0 and 2, where each number is equally likely to be drawn. For example, the odds that you receive opportunity cost = 1.15 are the same as the odds that you receive opportunity cost = 0.82 are the same as the odds that you receive opportunity cost = 0.23, etc. As such, each of the eight individuals in your group will be randomly assigned an opportunity cost and will formulate offers given this information. **All individuals in your group know only their own opportunity costs and that the other individuals in their group have opportunity costs drawn from the same distribution. You will not know the opportunity costs of any of your peers.**

After eight rounds, you will be randomly assigned to a new group of eight individuals. (The random assignments were made before this session by drawing numbers from a hat. The assignment will not be based on the offers made in previous rounds.) In addition, you will receive a new opportunity cost, drawn from the same distribution as before. Each of the other 23 participants in this room will also be randomly assigned to a new group of eight individuals, and will also draw new opportunity costs. This process will occur every eight rounds. If there are any questions about this process, please raise your hand and ask one of the researchers.

The experiment will be complete after 16 rounds. All experimental dollars will be converted to real dollars using a one-to-one ratio. Before the experiment begins, the researcher will briefly discuss the experiment with you using a PowerPoint presentation. There will also be five practice rounds where all 24 participants will participate in rounds of the auction. After these rounds, new opportunity costs and groups will be assigned, and the experiment will begin.

Summary

- At the beginning of the experiment, you will receive a randomly drawn opportunity cost between 0 and 2, with each value in that range being equally likely.
- Based on that opportunity cost, each round you will submit an offer to the buyer for your unit.
- The buyer has a budget, $4.42**,** with which to award contracts. The buyer accepts offers in ascending order, from smallest to largest until their budget is exhausted.
- In a given round, if you receive a contract, you will rent out your unit and receive your offer as payment for that round. (You will earn your offer instead of your opportunity cost as payment.)
- If you do not receive a contract, you will keep your unit and earn your opportunity cost as payment for that round.
- After each round, you will once again have possession of your unit, and will be able to participate in the auction during the next round.
- After eight rounds, you and the other 23 participants in the experiment will be randomly assigned to new groups of eight with new, randomly assigned opportunity costs. The budget will remain constant across all 16 rounds.

A.5 Power Point: Budget-Constrained Auction

Overview of Experiment

- Throughout this experiment you own one unit of an asset that you can either use yourself or rent out each round. If you keep the unit in a round you can use it yourself for a value which we call your opportunity cost. So, if you don't rent the unit you will be paid your opportunity cost by the experimenter for that round. If you do rent your unit you can not use it but will instead be paid a rent determined in an auction. In order for your unit to be rented, your offer must be one of the cheapest offers, until the budget is exhausted.
- Regardless of whether your unit was rented or not, at the beginning of every round, you will once again have possession of your unit, and will submit another offer for the opportunity to rent it.

Overview of Instructions

- You have been randomly assigned to a group of 8 individuals.
- At the beginning of the experiment, you will receive a randomly drawn opportunity cost between 0 and 2, with each value in that range being equally likely.
- You will receive a new randomly assigned opportunity cost after 8 rounds.
- The groups will also be randomly reassigned after 8 rounds.
- Based on your opportunity cost, each round you will submit an offer to the buyer for your unit.
- In a given round, if you receive a contract, you will rent out your unit and receive your offer as payment for that round. (You will earn your offer instead of your opportunity cost as payment.)
- If you do not receive a contract, you will keep your unit and earn your opportunity cost as payment for that round.

Overview of Instructions

- The buyer has a limited budget of $4.42. The buyer will accept offers in ascending order until their budget is exhausted.
- There will be five practice rounds, the results of which will not result in monetary rewards. These rounds are merely for instruction.
- Across these five rounds, the budget will change. The goal of these rounds is simply to detail how the software functions and to ensure that all participants fully understand how the auction works.
- After the five practice rounds, the budget will be fixed at $4.42 for all 16 rounds. These rounds will result in monetary rewards at the end of the experiment.


ParticipantSheet_April_18_2016_BC - Excel

	Round -4	Round -3	Round -2	Round -1	Round 0
Number of Participants	8	8	8	8	8
Budget	$10.00	$10.00	$3.00	$3.00	$2.00
Opportunity Cost	$1.85	$0.26	$0.41	$0.91	$0.64
Offer					
Results					
Payment	$0.00	$0.00	$0.00	$0.00	$0.00
Total Earnings					

A.6 Instructions: Provision Point Reverse Auction

INSTRUCTIONS

This experiment is a study of individual decision-making in a group setting. If you follow these instructions carefully and make informed decisions, you will earn money. The money you earn will be paid to you, in cash, after the experiment has concluded. We ask that you do not use any electronic devices during this experiment, including cell phones, tablets, etc. We further ask that you do not communicate with your peers in any capacity. If you have any questions, please raise your hand and the researchers will come to assist you.

In this experiment, you are a member of a group consisting of eight individuals. You and the other seven individuals each own one unit of a good that can be rented out each round. Each unit of the good is indistinguishable from any of the other units owned by your fellow participants. Additionally, each participant in your group will be given an individual valuation for their own unit of the good, which we will call their **opportunity cost (more details will follow)**. Individuals who do not rent out their unit will receive this opportunity cost as payment at the end of each round. A single buyer is interested in renting five units of the good each round. (The buyer is not interested in renting more than five units) However, the buyer has a limited budget and thus will pay individuals for their units using an **auction.** The auction will be conducted as follows:

- Each round, you will submit an **offer** representing the amount of money for which you would be willing to rent out your unit during that round. (Your offers will be capped at $7 each round. If you try to submit an offer higher than $7, you will be asked to enter a different offer.)
- Your peers will also submit their own offers for their units.
- The buyer will then rank these offers in ascending order and provide contracts to the lowest offer, then the second lowest offer, and so on until the fifth lowest offer.
- If you <u>do</u> receive a contract from the buyer, the buyer will take your unit (for that round) and **you will receive your offer as payment (for that round)**.
- If you <u>do not</u> receive a contract from the buyer, **you will keep your unit and receive your opportunity cost as payment for that round.**

However, the buyer is only interested in offering contracts to individuals in your group if they can afford at least **five** of the offers. From this point on, this number (five) will be referred to as the **funding threshold.** If, given the offers that your group submits, the buyer cannot afford the five lowest offers, then no individual will receive a contract, regardless of the magnitude of their offer. If the buyer can afford at least **five** offers then the buyer will offer contracts to the participants that submitted the five lowest offers, as described above.

An individual's opportunity cost (in experimental dollars) will be drawn from a **uniform distribution** from **0 to 2**, in increments of 0.01. In other words, you will randomly receive a number between 0 and 2, where each number is equally likely to be drawn. For example, the odds that you receive opportunity cost = 1.15 are the same as the odds that you receive opportunity cost = 0.82 are the same as the odds that you receive opportunity cost = 0.23, etc. As such, each of the eight individuals in your group will be randomly assigned an opportunity cost and will formulate offers given this information. **All individuals in your group know only their own opportunity costs and that the other individuals in their group have opportunity costs drawn from the same distribution. You will not know the opportunity costs of any of your peers.**

After eight rounds, you will be randomly assigned to a new group of eight individuals. (The random assignments were made before this session by drawing numbers from a hat. The assignment will not be based on the offers made in previous rounds.) In addition, you will receive a new opportunity cost, drawn from the same distribution as before. Each of the other 23 participants in this room will also be randomly assigned to a new group of eight individuals, and will also draw new opportunity costs. This process will occur every eight rounds. If there are any questions about this process, please raise your hand and ask one of the researchers.

The experiment will be complete after 16 rounds. All experimental dollars will be converted to real dollars using a one-to-one ratio. Before the experiment begins, the researcher will briefly discuss the experiment with you using a PowerPoint presentation. There will also be five practice rounds where all 24 participants will participate in rounds of the auction. After these rounds, new opportunity costs and groups will be assigned, and the experiment will begin.

Summary

- At the beginning of the experiment, you will receive a randomly drawn opportunity cost between 0 and 2, with each value in that range being equally likely.
- Based on that opportunity cost, each round you will submit an offer to the buyer for your unit.
- The buyer has a budget, $4.42**,** with which to award contracts. The buyer accepts offers in ascending order, from smallest to largest.
- For each round, if out of your group of eight, the buyer cannot afford the lowest five offers, then no contracts will be awarded. If the buyer can afford the five lowest offers, then exactly five contracts will be made with the participants who submitted the five lowest offers.
- In a given round, if you receive a contract, you will rent out your unit and receive your offer as payment for that round. (You will earn your offer instead of your opportunity cost as payment.)
- If you do not receive a contract, you will keep your unit and earn your opportunity cost as payment for that round.
- For additional clarification: in order to receive your offer as payment instead of your opportunity cost, your offer must be accepted by the buyer. For your offer to be accepted, your offer must be one of the five lowest, and the sum of the five

lowest offers must be less than the buyer's budget. If those two conditions are not met, you will receive your opportunity cost as payment.

- After each round, you will once again have possession of your unit, and will be able to participate in the auction during the next round.
- After eight rounds, you and the other 23 participants in the experiment will be randomly assigned to new groups of eight with new, randomly assigned opportunity costs. The budget and funding threshold will remain constant across all 16 rounds.

A.7 Power Point: Provision Point Reverse Auction

Overview of Experiment

- Throughout this experiment you own one unit of an asset that you can either use yourself or rent out each round. If you keep the unit in a round you can use it yourself for a value which we call your opportunity cost. So, if you don't rent the unit you will be paid your opportunity cost by the experimenter for that round. If you do rent your unit you can not use it but will instead be paid a rent determined in an auction. In order for your unit to be rented, there are two requirements:
  - 1. Your offer must be one of the five lowest offers submitted by your group.
  - 2. The total of the five lowest offers in your group must be less than the experimenter's budget.
- Regardless of whether your unit was rented or not, at the beginning of every round, you will once again have possession of your unit, and will submit another offer for the opportunity to rent it.

Overview of Instructions

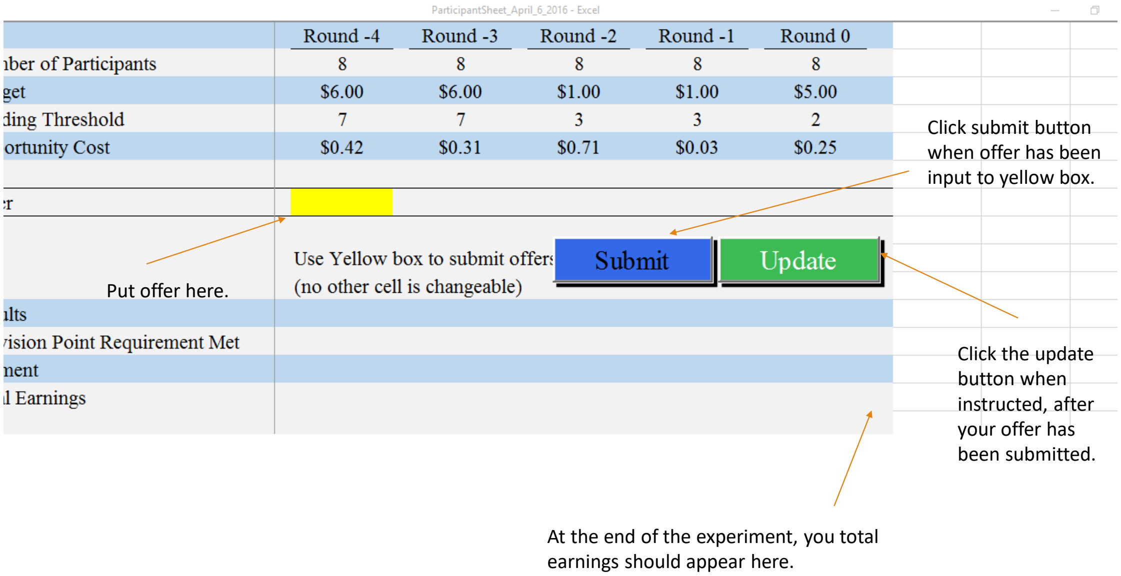
- You have been randomly assigned to a group of 8 individuals.
- At the beginning of the experiment, you will receive a randomly drawn opportunity cost between 0 and 2, with each value in that range being equally likely.
- You will receive a new randomly assigned opportunity cost every 8 rounds.
- The groups will also be randomly reassigned after 8 rounds.
- Based on your opportunity cost, each round you will submit an offer to the buyer for your unit.
- For each round, if out of your group of eight, the buyer cannot afford the lowest five offers, then no contracts will be awarded. If the buyer can afford the five lowest offers, then exactly five contracts will be made with the participants who submitted the five lowest offers.

Overview of Instructions

- In a given round, if you receive a contract, you will rent out your unit and receive your offer as payment for that round. (You will earn your offer instead of your opportunity cost as payment.)
- If you do not receive a contract, you will keep your unit and earn your opportunity cost as payment for that round.
- For additional clarification: in order to receive your offer as payment instead of your opportunity cost, your offer must be accepted by the buyer. For your offer to be accepted, your offer must be one of the five lowest, and the sum of the five lowest offers must be less than the buyer's budget. If those two conditions are not met, you will receive your opportunity cost as payment.
- After each round, you will once again have possession of your unit, and will be able to participate in the auction during the next round.

Overview of Instructions

- There will be five practice rounds, the results of which will not result in monetary rewards. These rounds are merely for instruction.
- Across these five rounds, the funding threshold and budget will change. The goal of these rounds is simply to detail how the software functions and to ensure that all participants fully understand how the auction works.
- After the five practice rounds, the budget and funding threshold will be fixed at $4.42 and 5, respectively, for all 16 rounds. These rounds will result in monetary rewards at the end of the experiment.



	Round -4	Round -3	Round -2	Round -1	Round 0
ıber of Participants	8	8	8	8	8
get	$6.00	$6.00	$1.00	$1.00	$5.00
ding Threshold	7	7	3	3	2
ortunity Cost	$0.42	$0.31	$0.71	$0.03	$0.25
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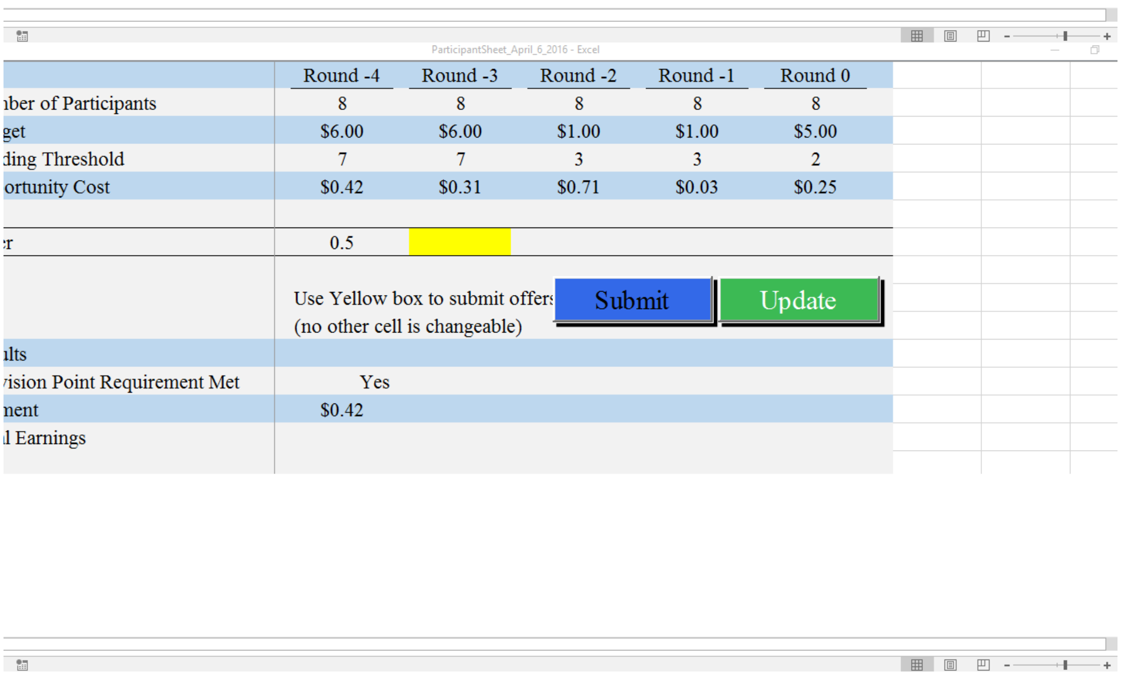

	Round -4	Round -3	Round -2	Round -1	Round 0
ıber of Participants	8	8	8	8	8
get	$6.00	$6.00	$1.00	$1.00	$5.00
ding Threshold	7	7	3	3	2
ortunity Cost	$0.42	$0.31	$0.71	$0.03	$0.25
ːr	0.5				
ults					
ision Point Requirement Met	Yes				
nent	$0.42				
l Earnings					

APPENDIX B

UNCERTAINTY IN PREFERENCES

B.1 Chocolate Bags

The following are pictures of the "circle" and "square" variety chocolates participants were given in the exchange asymmetry experiments.

Figure B.1: Bag of "Circle" Variety Chocolate

Figure B.2: Bag of "Square" Variety Chocolate

B.2 Exchange Asymmetry Scripts

Treatment Script

The following is the script the researcher will read during treatment sessions, and once all the participants have signed their consent forms. There will be no written instructions.

"This experiment is a study of individual decision-making under uncertainty. We ask that you do not use any electronic devices during this experiment, including cell phones, tablets, etc. We further ask that you do not communicate with your peers in any capacity. If you have any questions, please raise your hand and the researcher will come to assist you."

The researcher will distribute the chocolate now.

"You have been randomly given one of two varieties of chocolate. It is a gift. You own it. It is yours. I ask that you do not open the bag or consume the chocolate in the bag until the experiment has completed. Both circle and square variety bags contain the same weight of chocolate. Both varieties of chocolate are produced by the same company. On the desk in front of you, there is a short survey. Please complete this survey now."

The researcher will wait until the participants have completed the survey. Once all participants have completed the survey, the researcher will collect them.

"Thank you for completing the survey. Before the experiment concludes, you have the option of trading your bag of chocolate for the alternate variety. Before you make your decision, you will have the opportunity to taste a small amount of each variety. In the small bags on your desk, you will find two pieces of chocolate, one labeled 'square' and one labeled 'circle.' Feel free to try each variety now."

The researcher will wait until the participants have tried both pieces of chocolate.

"Thank you for participating in this experiment. If you would like to trade your chocolate, you may do so when you approach the front of the room to collect your show-up fee."

CONTROL SCRIPT "DESCRIPTIONS"

The following is the script the researcher will read during control sessions, and once all the participants have signed their consent forms. There will be no written instructions.

"This experiment is a study of individual decision-making under uncertainty. We ask that you do not use any electronic devices during this experiment, including cell phones, tablets, etc. We further ask that you do not communicate with your peers in any capacity. If you have any questions, please raise your hand and the researcher will come to assist you."

The researcher will distribute the chocolate now.

"You have been randomly given one of two varieties of chocolate. It is a gift. You own it. It is yours. I ask that you do not open the bag or consume the chocolate in the bag until the experiment has completed. The "square" variety of chocolate has been described as "luxurious", while the circle variety of chocolate has been described as "rich." Both circle and square variety bags contain the same weight of chocolate. Both varieties of chocolate are produced by the same company. On the desk in front of you, there is a short survey. Please complete this survey now."

The researcher will wait until the participants have completed the survey. Once all participants have completed the survey, the researcher will collect them.

"Thank you for completing the survey. Before the experiment concludes, you have the option of trading your bag of chocolate for the alternate variety. You may do so when you approach the front of the room to collect your show-up fee."

B.3 Exchange Asymmetry Survey

Please answer the following questions to the best of your ability.

1. The current United States Secretary of State is ________________________.
   How likely is it that your answer is correct? _____________________ percent.
   (enter likelihood between 0 and 100 percent)
2. Bucharest is the capital city of ______________________________________.
   How likely is it that your answer is correct? _____________________ percent.
   (enter likelihood between 0 and 100 percent)
3. The author of the novel *The Phantom of the Opera* is ___________________.
   How likely is it that your answer is correct? _____________________ percent.
   (enter likelihood between 0 and 100 percent)
4. The actor ________________ plays the Wolverine in the X-Men movie franchise.
   How likely is it that your answer is correct? _____________________ percent.
   (enter likelihood between 0 and 100 percent)
5. What does the acronym NASA stand for? ______________________________.
   How likely is it that your answer is correct? _____________________ percent.
   (enter likelihood between 0 and 100 percent)
6. Montgomery is the capital of the state _________________________________.
   How likely is it that your answer is correct? _____________________ percent.
   (enter likelihood between 0 and 100 percent)
7. The car company Volvo has its headquarters in the country _______________.
   How likely is it that your answer is correct? _____________________ percent.
   (enter likelihood between 0 and 100 percent)
8. The square root of 729 is ____.
   How likely is it that your answer is correct? _____________________ percent.
   (enter likelihood between 0 and 100 percent)

B.4 Exchange Asymmetry Trade Sheet

The following is a picture of the small piece of paper participants used to make their trade decisions.

Figure B.3: Exchange Asymmetry Trade Sheet

I would like to trade my (Square/Circle) (circle one) variety chocolate for the (Square/Circle) (circle one) variety chocolate.

Yes or No (Circle one)

Date: ______________________________ Experiment #: ___________________________

B.5 WTA/WTP Disparity Instructions: Treatment

The following are the instructions, page by page and as they would have appeared on a computer monitor, for a participant not endowed with chocolate who incorrectly answered the quiz question and submitted a value = 1.6 for the practice asset.

Instructions

This experiment is a study of individual decision-making under uncertainty. If you follow these instructions carefully and make informed decisions, you will earn money and possibly chocolate. The money you earn will be paid to you, in cash, after the experiment has concluded. We ask that you do not use any electronic devices during this experiment, including cell phones, tablets, etc. We further ask that you do not communicate with your peers in any capacity. If you have any questions, please raise your hand and the researchers will come to assist you.

Next

Instructions

You have been given \$10 (your show-up fee plus an additional \$5.) Some of your peers have also been given a bag of chocolate. You do not currently own any chocolate, but you will be given the opportunity to purchase some chocolate at the end of the experiment.

Next

Instructions

Before you have the chance to buy some chocolate, you will be given the opportunity to buy some assets which will yield random returns. You will have the opporunity to buy these assets, depending on how much you value them.

The purchasing of assets works as follows: 1) You will be given information about some assets which yield random returns. For example, an asset might yield $2 exactly 80% of the time and $0 the other 20% of the time. 2) You will state the amount of money you would be willing to pay to buy the asset. 3) A random number will be drawn. If that random number is less than your stated value, you will purchase the asset and the random number (not your stated value!) will be deducted from your current monetary earnings. If you buy the asset, you will be paid based on the return to your asset. If, however, the random number is greater than your stated value, you will not buy the asset, and you will keep your money. Recall that you start the experiment with $10.

For example, suppose that you have a chance to purchase an asset which yields $2 exactly 80% of the time and $0 otherwise. Suppose you state that your value for this asset is $1.20. If the drawn random number is $1.50, you will not buy the asset because the random number ($1.50) is greater than your stated value ($1.20). Suppose, instead, that the random number is $1. Then, because the random number is less than your stated value, you purchase the asset for $1 and you will be paid depending on the return to the asset.

Next

Instructions

The optimal strategy for this mechanism is always to state your true value for the asset. This may seem counter-intuitive, but consider the following example. Suppose that there is an asset which yields $2 exactly 100% of the time. Then your true value for this asset is $2. Suppose that instead of stating the amount of money that you would actually be willing to pay for the asset ($2), you state $2.50. If the drawn random number is $2.70, then you keep your money and do not buy the asset. But, if the random number is $2.40, then because your stated value ($2.50) is higher than the random number, you buy the asset for $2.40, even though $2.40 is worth more to you than the asset. Thus, stating a value higher than your true value can only result in outcomes that are either worse, or as good as, if you stated your true value.

Next, suppose that instead of stating your true value, you stated a value less than your true value, say $1.50. Suppose that the drawn random number is $1.75. Then because $1.75 is higher than $1.50, you do not buy the asset for $1.75. In this case, you are worse off than if you had stated your true willingness to pay of $2, because if you stated $2, you would buy the asset for $1.75, and be better off by $0.25.

If you have any questions, or would like a clarification, please raise your hand now.

Next

Instructions

Consider the following example. Suppose that you have the opportunity to buy an asset which yields a return of $2.50 100% of the time.

What should you submit for you stated value to maximize your profit?

Next

Instructions

You answered 2.0. This is incorrect. You submitted a stated value less than your true value. If the random number is between your stated value (2.0) and your true value ($2.50), you would miss an opportunity to buy the asset for less than it is worth to you. If you submit your true value for your stated value, you will never miss an opportunity to earn profit. If this is unclear, please raise your hand now.

Next

Instructions

On the next page, there will be a practice round where you will have the opportunity to buy an asset. You will not pay real money for this asset, nor will this asset yield any real money. This will merely be for practice. Following this practice round, you will be presented with a sequence of five assets which will yield real returns, and which you can buy for real money using the mechanism described in the instructions. Finally, you will have the opportunity to buy chocolate using this mechanism at the end of the experiment. Click next when you are ready to proceed.

Next

Practice Round

There is an asset which yields $3 exactly 60% of the time, and $0 otherwise. You have the opportunity to purchase this asset by stating your value for the asset. A random number will be drawn, and if that random number is less than your stated value, you will buy this asset and pay the random number. You will then be paid based on the yield of the asset. If the random number does not exceed your stated value, you will not buy the asset and will keep your money. (Note: this is a practice round, and so will not result in monetary payments.)

What is your value for this asset?

Next

Practice Round, Results

Your stated value was 1.7. The random draw was 1.84. You submitted a stated value less than the random draw, so you do not buy the asset.

The asset yielded $0. If you own the asset, you will be paid $0.

This was a practice round, so you earned no money. The following three rounds will be played for real money.

Next